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CONTENTS

Brittle Fracture of Steel Pressure Vessels
By A. Cracknell

Filler Composition in Aluminium Welding
By J. G. Young

Cracking in Austenitic Steels
By R. N. Younger, J. C. Borland and R. G. Baker

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Cover Illustration
see p. 588

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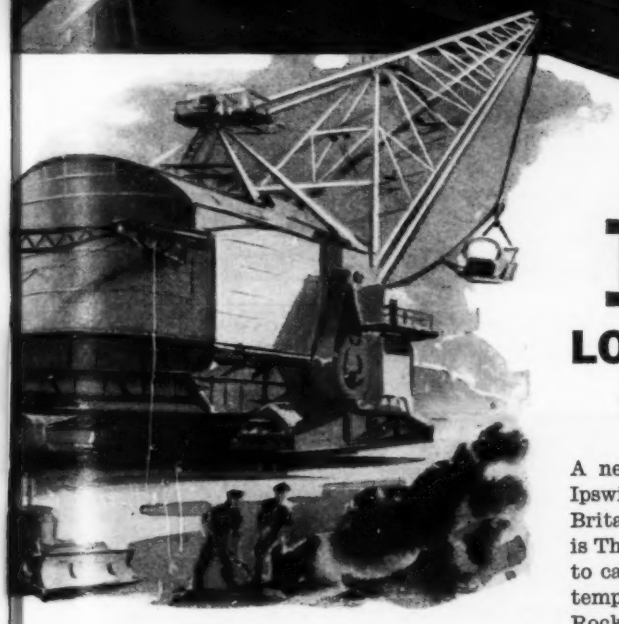

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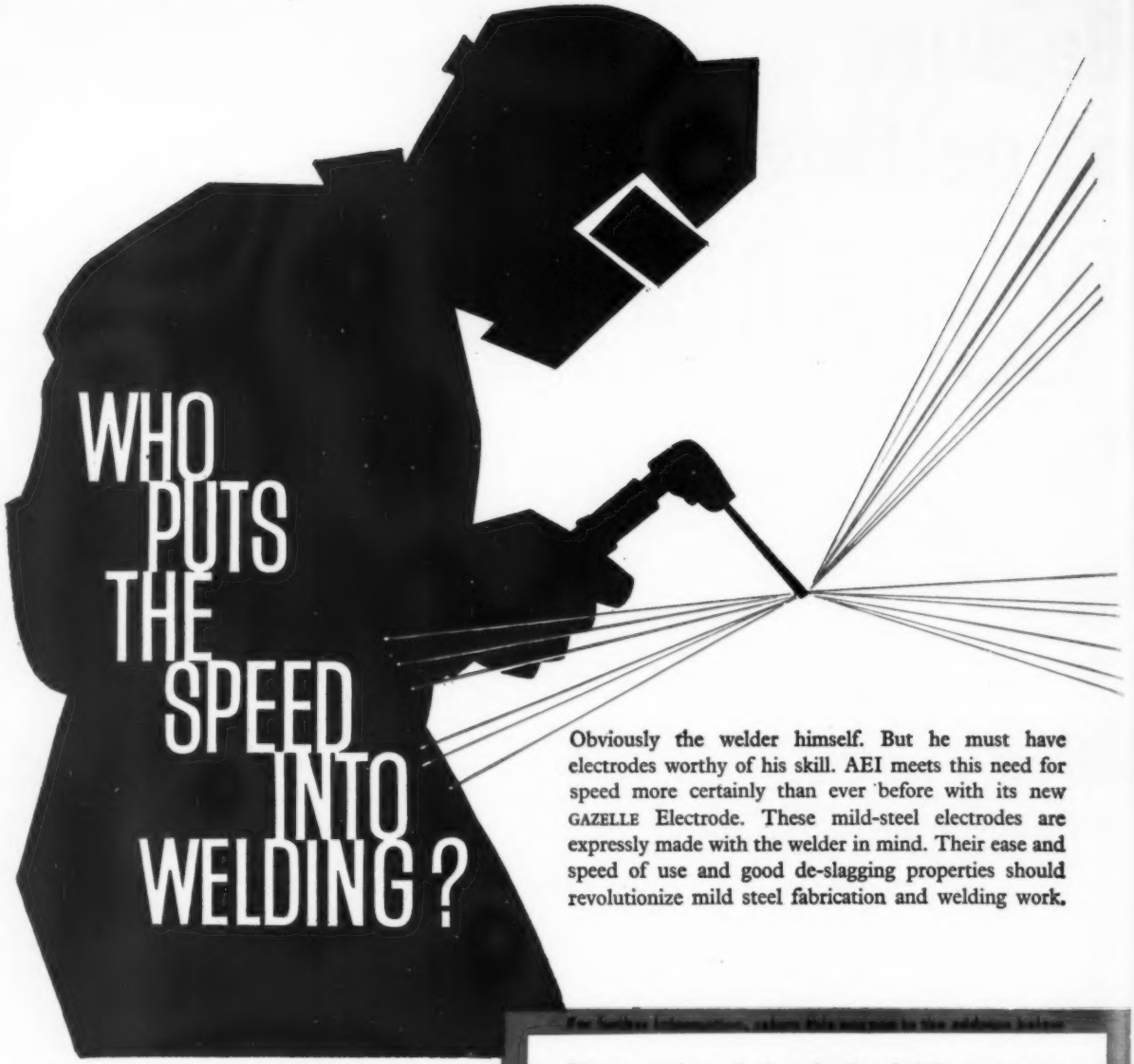

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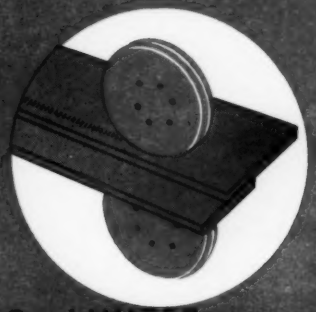

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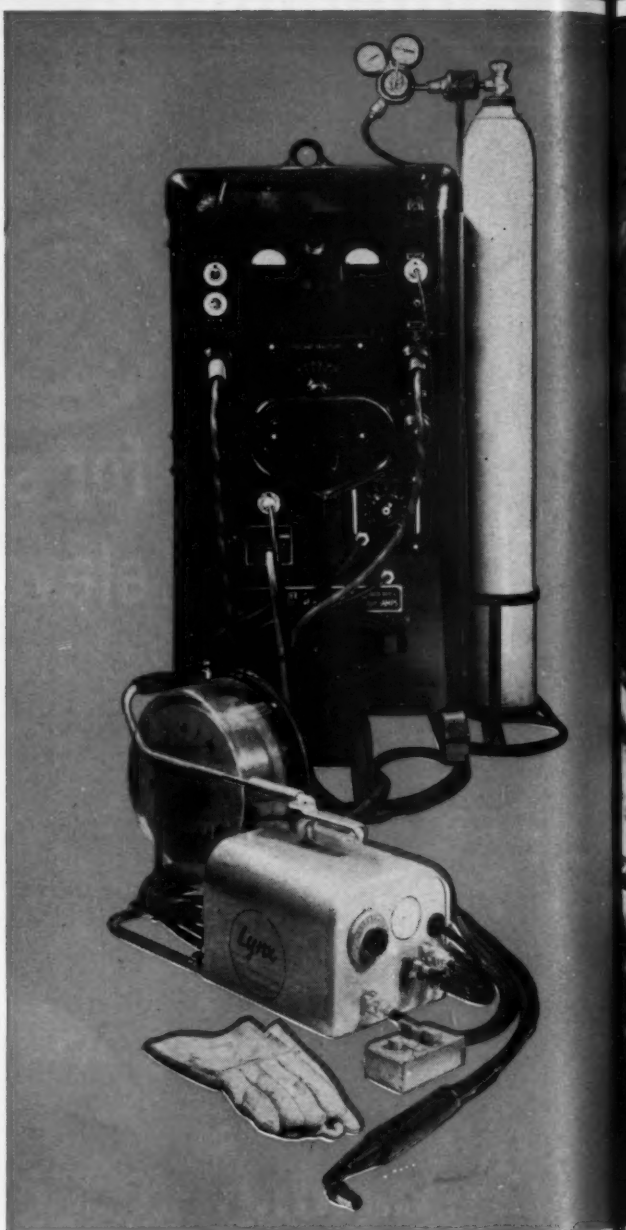

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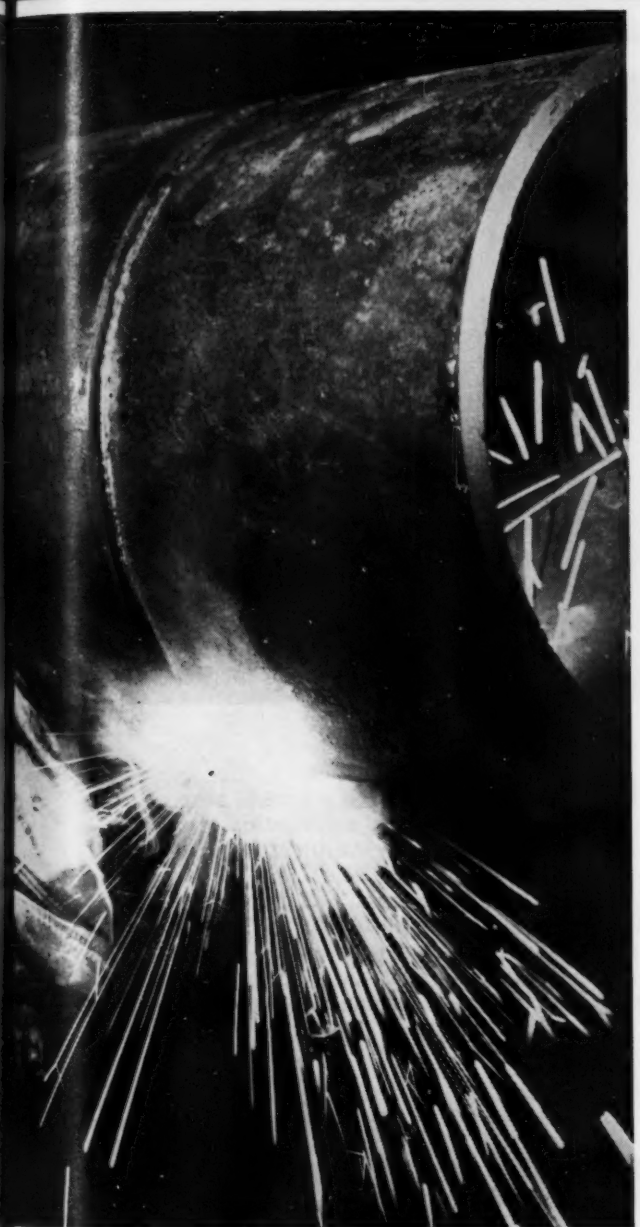

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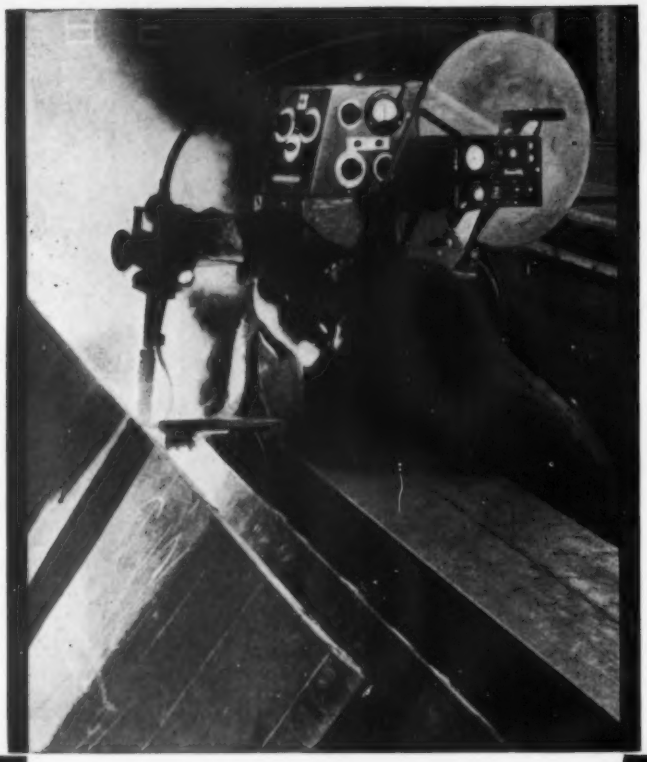

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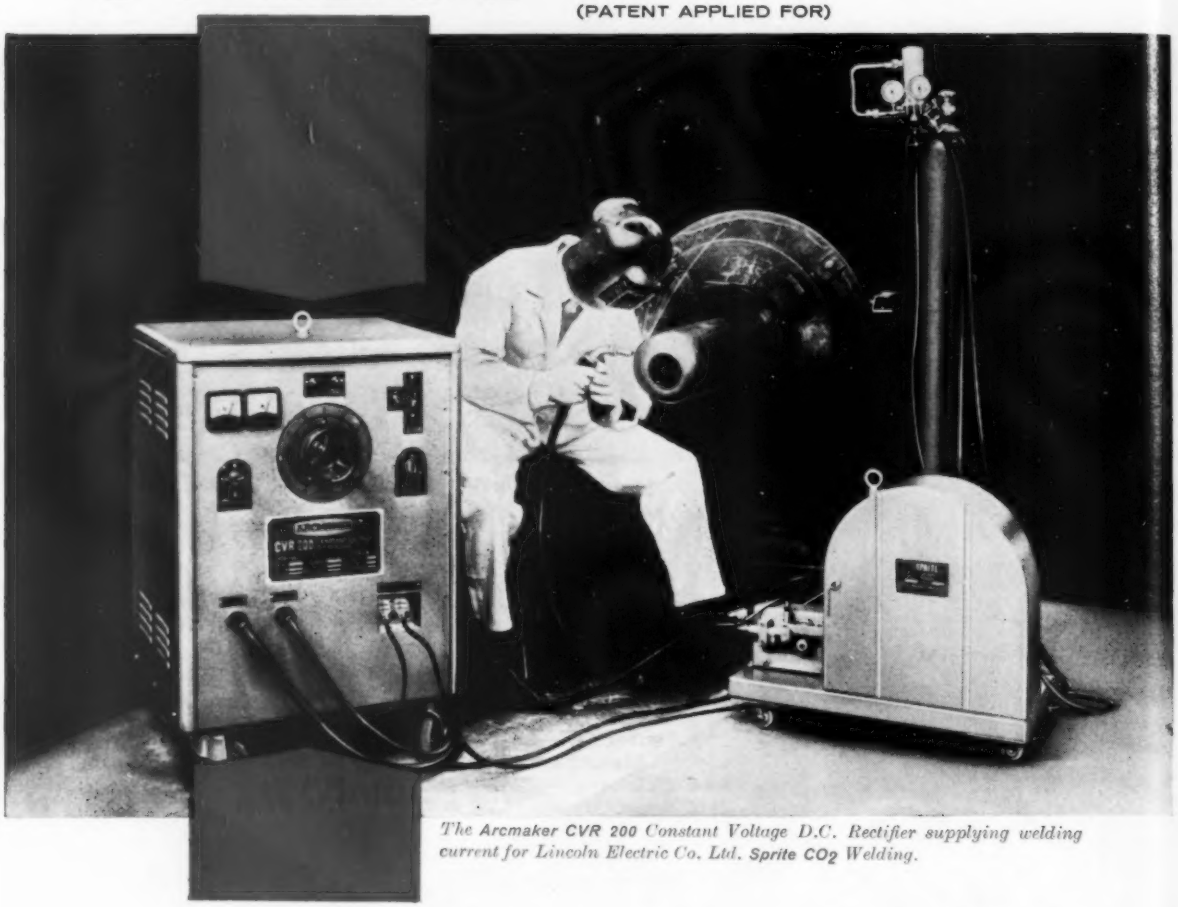

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CONTENTS

INSTITUTE OF WELDING

561 **Brittle Fracture of Mild Steel Pressure Vessels**
By A. Cracknell

BRITISH WELDING RESEARCH ASSOCIATION

568 **Significance of Filler Metal Composition in Aluminium Alloy Welding**
By J. G. Young

575 **Heat-Affected Zone Cracking of Two Austenitic Steels during Welding**
By R. N. Younger, J. C. Borland and R. G. Baker

579 **Heat-Affected Zone Cracking in Welded Austenitic Steels During Heat Treatment**
By R. N. Younger and R. G. Baker

588 NEWS AND ANNOUNCEMENTS

592 CURRENT LITERATURE

Supplement

INTERNATIONAL WELDING

83s **Reports on Fatigue Failures**

87s **Recommended Practice for the X-Ray Inspection of Fusion Welded Joints on Aluminium and Its Alloys and Magnesium and Its Alloys up to 2 Inches (50 mm) Thick**

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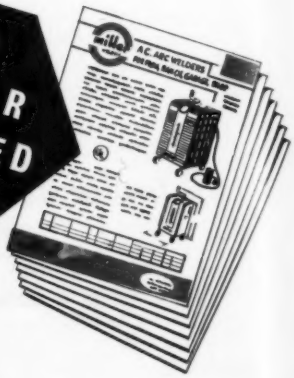

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Welding TECHNOLOGY

Brittle Fracture of Mild Steel Pressure Vessels

By A. Cracknell, B.SC. PH.D.

Robertson-type tests and bursting tests at selected temperatures have been made on small pressure vessels to demonstrate the brittle fracture characteristics of two steels.

The tests have shown that the biaxial stresses did not change the expected behaviour: cracks did not propagate if the temperature was too high or the stress too low.

The results have been related to the behaviour of the same steels in the Charpy V-notch impact test. A high average impact value is shown to give no certain protection against brittle fracture.

Introduction

THE phenomenon of low-temperature brittle fracture of mild steel is now well known, and, in the years since World War II when it was first recognised as a distinct problem, many of the factors involved in it have been established. From the practical aspect, particular importance is attached to the work by Robertson,[1] Wells[2] and Kennedy[3]. Robertson showed that brittle cracks would not propagate if the temperature was above some critical value T_R or if the applied stress was less than about 4 tons/sq.in. σ_R. These results were extended by Wells and Kennedy who showed that at temperatures below T_R, as-welded plates containing intentional defects could fracture at any stress up to the yield stress. If the fracture occurred at a very low applied stress the crack was limited in length and spread only through the residual (tensile) stress field of the weld. When the fracture occurred at somewhat higher applied stress (though still less than the yield stress) this was sufficient to propagate the crack through the residual stress field and out to the edges of the plate. Such cracks occurring in service could lead to a catastrophic failure.

More important still, however, was the finding that, if the residual stress field was removed, either mechanically or thermally by a stress relief treatment at 650°C., cracks formed only at the yield stress and after a small amount of deformation had occurred.

These observations of the effects of residual stresses on the initiation of brittle fractures form a useful basis to a design philosophy for structures in which the operating stresses and temperatures are well defined, *e.g.*, for pressure vessels for use at low temperatures in the chemical industry. The conclusions are that:

(*a*) If a vessel cannot be stress relieved after welding, then it is only safe from brittle fracture if operated at a temperature above T_R at which brittle cracks cannot propagate.

(*b*) If stress relieving is feasible, then this temperature limitation is removed and the vessel can operate below T_R. The design stress used is so low relative to the yield stress that there is no chance of a brittle crack being initiated at a defect under normal operating conditions.

It should be recognised that if a crack is initiated, due to some improbable combination of circumstances leading to local yield point stresses, then the resulting failure could well be catastrophic.

(*c*) If the design stress is limited to a value of the order of 2 tons/sq.in. then again this particular temperature limitation is removed, for a brittle crack cannot propagate if the stress is so low.

Manuscript received 10th August 1961.

Dr. Cracknell is a Technical Officer in the Metallurgical Section, Engineering Developments Department, I.C.I. Ltd., Billingham.

Now all the work on which the above philosophy is based was done on flat plates under uni-axial tension, whereas the walls of pressure vessels carry substantially biaxial stresses. In consequence, as part of a wider programme in which the properties of metals at low temperatures were examined, confirmation was sought that the type of result obtained by Robertson applied also to pressure vessels. The work was further extended to include an examination of the behaviour of stress-relieved vessels under gross overload and containing intentional defects, and the changes in behaviour as the test temperature was reduced through the transition range. As such, the latter was an extension of tests reported some time ago by Keating and Mathias.[4]

Experimental Methods

Three different types of experiment have been made using pressure vessels as specimens to obtain information on the points outlined in the Introduction.

The first series of tests was made to determine the highest temperature at which a brittle crack would propagate, and the corresponding impact values of Charpy V-notch specimens. In these tests, experimental vessels were pressurised to give a tangential stress of 7·7 tons/sq.in. (calculated from the mean diameter formula), somewhat higher than the normal design stress but well below the yield stress of the material. A temperature gradient was established along the length of the vessels by cooling one end with liquid nitrogen while warming the other with a ½ kW heater. When the temperatures indicated by thermocouples strapped on at 5 in. intervals along a vessel were steady, a crack was initiated by firing a nail from a gun into a notched web welded about 10 in. from the cold end of the vessel. This crack propagated up the vessel until it was arrested. The arrest temperature was then determined by reference to the measured temperature gradient.

The second set of tests was made to give an indication of the minimum stress required to propagate a brittle crack in a pressure vessel. For this the vessels were cooled to a uniform temperature of −60° to −70°C. (well below the normal transition temperature) and after stressing to either 3, 4 or 5 tons/sq.in. a crack was initiated with the gun. Depending on the applied stress, this crack either did or did not propagate.

In the third series of tests, vessels made with a sharp notch defect were slowly pressurised at a given temperature until they burst. These tests were made over a range of temperatures, both to give the transition temperature from ductile to brittle behaviour and so that the behaviour of the vessels could be observed under widely differing conditions.

Though plate thickness is known to have an appreciable effect on the temperatures at which steels show brittle behaviour, it was decided to limit the scope of the tests and to make all the vessels with the same wall thickness.

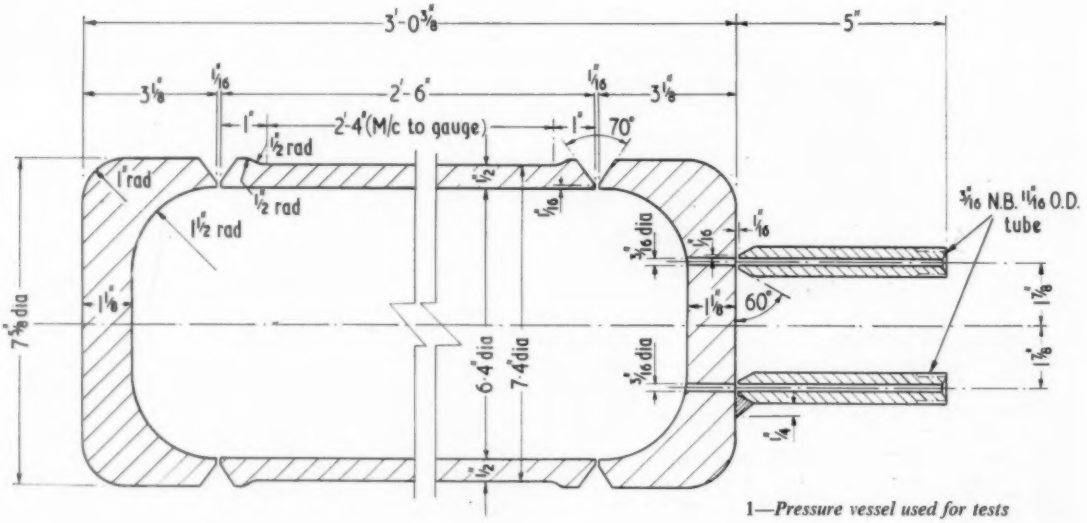
Materials

Two steels were used for the tests, one Si-killed and the other Al-killed. They were obtained as hot finished seamless tubes 7⅝ in. o.d. × ⅝ in. wall thickness. (Only one cast was used for each type of steel). The Al-killed steel was of a quality that is normally expected to have an average Charpy V-notch impact value at −50°C. of better than 15 ft-lb, with no specimen below 12 ft-lb. However, tests showed that the steel used did not meet these criteria even at −15°C.

Analyses

Only two pipes from each cast were used in the tests These had the following analyses:

	C, %	*Si*, %	*Mn*, %	*S*, %	*P*, %
Si-killed steel	0·14	0·31	0·48	0·04	<0·03
	0·13	0·31	0·48	0·03	<0·03
Al-killed steel	0·13	0·25	0·75	0·03	<0·03
	0·14	0·28	0·71	0·04	<0·03



1—Pressure vessel used for tests

	Ni, %	*Cr*, %	*Mo*, %	*Cu*, %	*Al*, %*	N_2, %
Si-killed steel	0·16	0·17	<0·1	0·2	<0·05	0·010
	0·15	0·16	<0·1	0·2	<0·05	
Al-killed steel	0·15	0·14	<0·1	0·3	<0·05	0·005
	0·15	0·18	<0·1	0·3	<0·05	

* The soluble aluminium content of even an aluminium-killed steel is expected to be only about 0·017%.

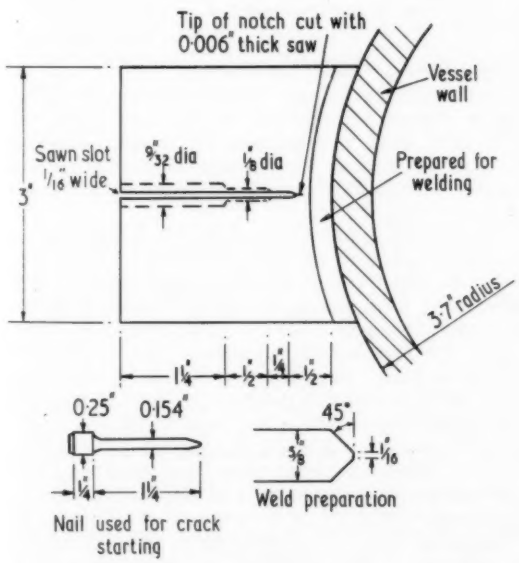
Details of the test vessels

Figure 1 is a drawing of the pressure vessels used in this work. They were 7·4 in. o.d. with $\frac{1}{2}$ in. walls and 30 in. long over the parallel portion and were made from pieces of pipe machined only on the outside. The end caps were welded on and the vessels were then stress relieved at 650°C. In some tests a close-fitting steel core bar was enclosed in the vessel to reduce the amount of energy to be dissipated at the instant of fracture.

Crack starters

The type of crack starter used depended on the test being made. When the tests were designed to assess the tendency of cracks to propagate in elastically-stressed metal, the cracks were initiated by impact loading. A slotted web, shown in Fig. 2, was welded on the vessel and a nail was fired into the slot from a specially designed gun. The forces were such that at low temperatures, even in the absence of pressure in the test vessel, the nail caused a crack that ran about 1 in. on both sides of the web.

For the simple bursting tests a short circumferential brittle weld was deposited at the mid-point of the length of vessels. These deposits, made with a hard-facing electrode giving a hardness of 250 D.P.N., were notched parallel to the length of the vessel using a saw blade 0·006 in. thick. Tests on bend specimens showed that these deposits cracked when the base metal yielded.



2—*Details of web attachment and nail used to initiate cracks*

Cooling and pressurising arrangements

Arcton 9 ($CF\,Cl_3$) was used as the pressurising fluid in all tests. This had the advantages of being non-inflammable, non-toxic, and having a very low freezing-point so that there was no possibility of it solidifying under pressure at the temperatures that were of interest. It had the disadvantage of a boiling-point only a little above room temperature and so tended to form a vapour lock during the suction stroke of the pump. This difficulty was overcome by cooling the Arcton and the pump to about +10°C. before the start of a test.

A small pressure vessel was interposed between the test vessel and the hydraulic pump. By cooling this vessel to about 10°C. below the temperature of the test vessel, heating, as a result of the transfer of hydraulic fluid, could be prevented.

For both the simple bursting tests and the tests to determine the minimum stress for brittle propagation, the intermediate and the test vessels were held in insulated containers and cooled with solid carbon dioxide–methanol mixture. After the specimen had been at the selected temperature for at least $\frac{1}{2}$ hr the methanol was drained off and the test commenced. Even in the tests in which the vessels were grossly deformed the temperature rise, during the 30 min or so required to reach the bursting pressure, was only about 5°C.; it was thus a simple matter to ensure that vessels burst within a few degrees of a selected temperature. Five thermocouples spaced along the length of each vessel were used to check the uniformity of temperature. In no case was the temperature variation more than 3°C.

In those tests in which a temperature gradient had to be established along the length of a vessel the top few inches were warmed with a close-fitting $\frac{1}{2}$ kW electric heater and the bottom 8 in. cooled first to about −70°C. with solid carbon dioxide–methanol and then to −196°C. with liquid nitrogen.

Once the required temperature gradient had been established and held for about $\frac{1}{2}$ hr. it only took a few minutes to pressurise the vessel, check the temperature distribution, and fire the gun to initiate a crack.

Experimental Results

Crack propagation up a temperature gradient

Duplicate tests were made on each of the two steels that were available. These vessels were tested without core bars. Figure 3 is a photograph of one of the Si-killed steel vessels, showing the distribution of temperature and the point x at which the crack was arrested. The position of the web that was used in starting the crack can readily be seen.

The point x only marks the end of the crack on the external surface of the vessel, for when the crack was opened for examination the tip of the crack inside the vessel wall was found to have run ahead of the crack at the surfaces. The difference between the temperatures at the tip of the crack and at the point where the crack met the surface was about 10°C.

In all cases, the bottom ends of the vessels were extensively cracked; this is not surprising since they were cooled to −196°C. to establish the required temperature gradient.

Table I

Crack arrest temperatures

Vessel No.	*Type of Steel (Si- or Al-killed)*	*Tangential Stress, tons/sq.in.*	*Range of Temperature over the Crack End, °C.*	
			Lowest	*Highest*
2/6	Al	7·7	−11	−1
4/6	Al	7·7	−11	−4
2/3	Si	7·7	−12	−5
4/3	Si	7·7	−13	−6

The measured arrest temperatures are given in Table I.

3—*Vessel in which a brittle crack, initiated by impact, has propagated up a temperature gradient to point* x. *Temperatures marked along length of vessel are in °C.*

Effect of applied stress on crack propagation

These tests were made to find the minimum stress for propagating a brittle crack. The vessels were cooled to a low but fairly uniform temperature (−60° to −70°C.), stressed to the required level, and then cracked by firing a nail into the web.

As has been pointed out, even in the absence of an applied stress, a crack about 2 in. long was formed by the impact of the nail. The length of the crack was unaffected by low applied stresses, but as the applied stress was increased long cracks tended to be formed. An example of each type of failure is given in Fig. 4.

Only a small number of vessels was available for these particular tests, and when a vessel failed by forming a short crack this was welded up so that the vessel could be re-used. The new web was welded on a different part of the vessel.

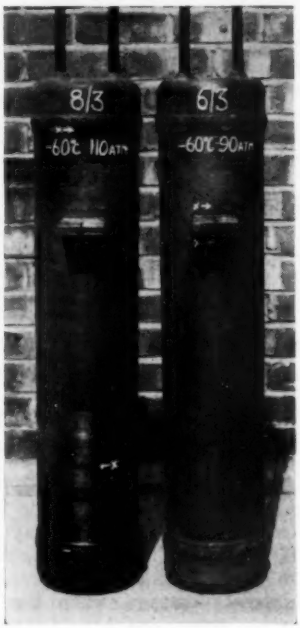
Table II summarises the results obtained.

Table II

Summary of applied stress tests

*Vessel No.**	*Type of Steel (Si- or Al-killed)*	*Tangential Stress. tons/sq.in.*	*Crack Length (Long or Short)*
6/3	Si	3	S
22/2		3	S
6/3		3	S
6/3		4	S
30/2		4	L
8/3		5	L
6/6	Al	3	S
6/6		3	S
6/6		3	L
8/6		4	L

* These vessels were tested without core bars.

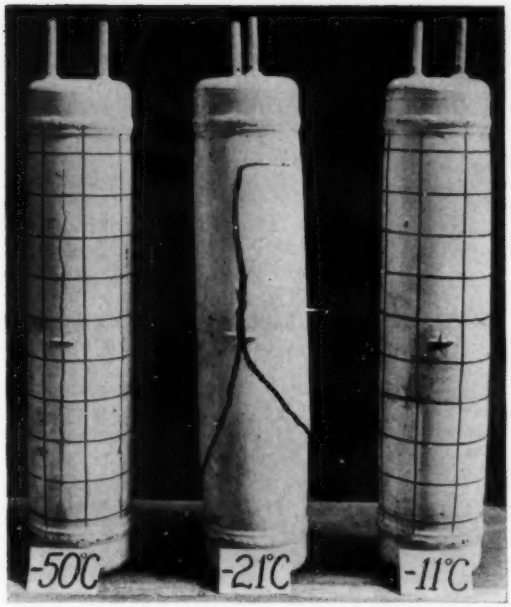


4—*Showing effect of applied pressure on extent of crack propagation. Cracks have run between points* x. *Tangential stress 5 tons/sq.in. in left-hand vessel; 4 tons/sq.in. in right-hand vessel*

Vessels burst by the application of pressure

In the two sets of tests described earlier, relatively lightly stressed vessels were burst by the application of a shock load, whereas here the vessels were burst by slow application of pressure. Observations were made of the variations with temperature of the ductility and type of fracture.

By bursting vessels at selected temperatures, it was relatively simple to determine the temperature range in which the fractures changed from short cracks, about 1 in. long, into brittle cracks that appeared to be limited in length only by the size of the test vessels. Figure 5, which is a photograph of three vessels after they have burst, illustrates the marked change in the extent of fracturing that can occur at low temperatures. The right-hand vessel, which was tested at −11°C., initially cracked in a brittle manner on a longitudinal plane. As the crack spread away from the crack starter very heavy shear lips formed and there was a considerable reduction in thickness of the metal at the tip. The energy absorbed as this crack spread was so great that it could only propagate about 1 in. before the contents of the vessel had discharged and released the pressure.



5—Fractures in vessels pressurised until they burst

At the lower test temperatures long brittle cracks formed and these tended to fork and run round as well as along the vessel. There were only two cases in which the crack did not deviate in its passage along the vessel, as shown on the left of Fig. 5; it may be significant that both these vessels were tested at the lowest temperatures used, about −50°C.

No attempt was made to determine accurately the yield and bursting pressures but it was noticed that all the vessels yielded at about 410 atm and burst at 600 ±20 atm. These pressures correspond to tangential stresses of 18·6 and 27·1 tons/sq.in., calculated from the mean diameter formula and the original dimensions of the test vessels. The difference between the yield and bursting pressures indicated that the vessels deformed appreciably before fracture, and this was confirmed by measurement. It was found that the Al-killed steel vessels had a circumferential strain at the middle of ≃ 4–6% irrespective of whether they ultimately failed in a ductile or a brittle manner; the Si-killed steel vessels gave circumferential strains of 4–10%.

In most of these tests the vessels had a close-fitting core bar to reduce the amount of energy to be dissipated when fracture occurred. Two tests were made to find if stored energy had a significant effect on the bursting characteristics of vessels tested only a little above their ductile–brittle transition temperature. These variations of stored energy were obtained by omitting the steel core bars and in one case by completely filling the test vessel with Arcton 9, in the other case by pre-pressurising the vessel with 5 atm of nitrogen before admitting the hydraulic fluid. No effect of stored energy was detected, and both vessels failed in a ductile manner.

The results of these bursting tests are summarised in Table III.

It will be seen from these tables that the transition from ductile to brittle tends to spread over about 10°C., and within this range the fractures can either be ductile or brittle.

Table III

Effect of test temperature on the behaviour on bursting of mild steel pressure vessels

Vessel No.	*Test Temp., °C.*	*Type of Fracture*[1]	*Circumferential Strain, %*[2]	*Remarks*
Silicon-killed steel				
24/2	+2	D	10	
26/2	0	D	8	
7/2	−5	B	6	
3/2	−11	D	10	
5/2	−11	B	8	
9/2	−16	B	7	
13/2	−21	B	8	
11/2	−50	B	4	Single straight crack
32/2	+4	D	11	No core bar
28/2	+2	D	7	No core bar, pre-pressurised with 5 atm nitrogen
Aluminium-killed steel				
5/1	−15	D	4·7	
16/1	−16	D	4·7	Cracked at a weld crater
7/1	−20	B	5·5	
18/1	−21	D	5·5	
3/1	−30	B	4·5	
20/1	−55	B	4·5	

[1] B=Long brittle fracture
D=Short crack terminated because of heavy plastic deformation

[2] The circumferential strain was measured at the point of maximum bulge. These measurements should not be regarded as accurate to better than ½% strain.

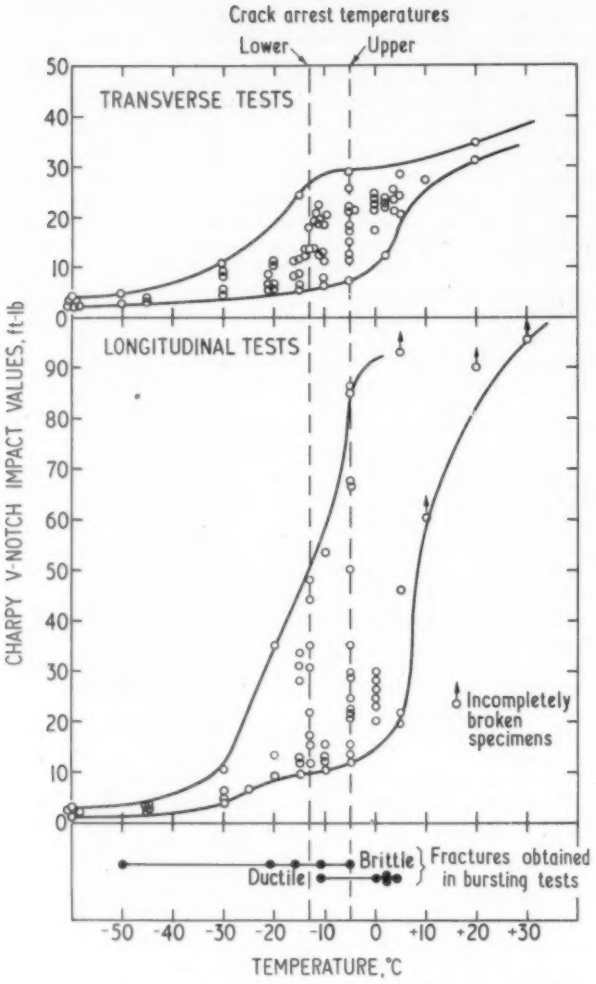
Mechanical tests

Both longitudinal and transverse tensile and Charpy V-notch impact tests were made on specimens cut from the pipes. The results of the tensile tests were as follows:

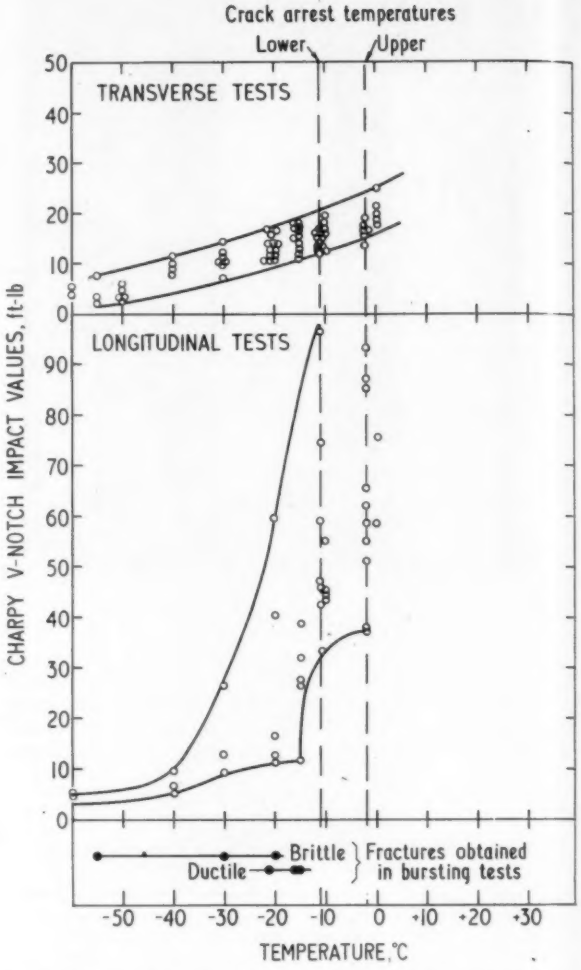
Material	*Longitudinal or Transverse*	*Yield Point, tons/sq.in.*	*U.T.S. tons/sq.in.*	*Red. in Area, %*	*% Elong.*
Al-killed	L	15·6	27·3	69	42
steel	T	16·4	27·5	59	38
Si-killed	L	15·9	26·7	67	40
steel	T	16·8	27·0	61	38

The impact specimens were notched radially, *i.e.*, through the thickness of the pipe. Thus the plane and direction of propagation of the cracks in the transverse impact specimens are similar to the plane and direction of longitudinal cracks in the pressure vessels. The wall thickness and curvature were sufficient for transverse specimens to be cut without the need to flatten the pipe.

Impact transition curves for longitudinal and transverse specimens of the two steels are plotted in Figs. 6 and 7 and superimposed on these are the types of fractures obtained in the bursting tests and the temperatures at which cracks were arrested in vessels with a temperature gradient.



6—*Impact transition curves, crack arrest temperatures, and types of fracture in bursting tests (Si-killed steel)*



7—*Impact transition curves, crack arrest temperatures, and types of fracture in bursting tests (Al-killed steel)*

Discussion of Results

It is immediately apparent from Figs. 6 and 7 that there was considerable scatter in the results of impact tests on longitudinal specimens. This is unfortunate, for it means that the transition temperatures obtained with pressure vessels cannot be related simply to the results obtained with longitudinal impact specimens. Nevertheless it is apparent that the changes in behaviour of the pressure vessels do occur in the temperature range in which the impact values of longitudinal specimens change markedly.

The impact values obtained with transverse specimens change much less rapidly with temperature. For the Si-killed steel there is a fairly well-defined range of temperatures within which the impact values increase by a moderate amount, but for the Al-killed steel there was no indication of a transition. Thus, even though these transverse specimens cracked along a path similar to that followed by cracks in the pressure vessels, they are not as useful as longitudinal specimens for indicating the temperature at which the fracture behaviour of pressure vessels is likely to change.

The mean and minimum impact values corresponding to the temperatures at the extreme ends of the cracks in the crack arrest tests, are given in Table IV.

Table IV

Charpy (V-notch) impact values corresponding to the crack arrest temperatures

(Longitudinal specimens)

Steel	*Temperature, °C.*	*C 120V (min), ft-lb*	*C 120V (average) ft-lb*
Si-killed	−13	10	26·5
	−5	12	38·6
Al-killed	−11	33·5	53·4
	−2	37	63·2

Specifications calling for impact tests (*e.g.*, BS 2762, Grades ND1, ND2 and ND3) commonly require an average impact value of 20 ft-lb from three (longitudinal) impact specimens with no individual result below 15 ft-lb. Retests are allowed in that specification if only one specimen gives less than the specified minimum individual value, provided that the average exceeds the specified minimum average. The above results show that very high average impact values may be associated with low individual values at the arrest temperatures. Since a high average impact value is no guarantee against brittle failure at the test temperature it would be more reasonable to base specifications on the minimum energy to be exceeded by all the specimens in the test group.

A further point clearly shown in Table IV is that the crack arrest temperatures of the two steels correspond to different levels of impact values. It would be unfair to generalise about the very high impact values of the Al-killed steel at the crack arrest temperatures, since this particular sample does not appear to be representative of its class. However, it has been reported on several occasions that crack arrest temperatures correspond to higher impact values in steels specially treated to give good impact properties at low temperatures. Though an appreciable premium is paid for these steels it is apparent that the benefits so obtained may be partly illusory.[5,6]

It will also be noted that the crack arrest temperatures of the Al-killed steel are appreciably higher (10–20°C.) than the highest temperature at which brittle fractures were obtained in the simple bursting tests (*see* Fig. 7). This difference is not found in the results obtained with the Si-killed steel (Fig. 6), but is not thought to be significant since the two tests were made under vastly different conditions.

Too few vessels were available for the limiting stress for crack propagation to be determined precisely, and in the case of the Al-killed steel a long crack was formed at the lowest stress at which tests were made. The Si-killed steel was slightly more consistent and gave short cracks in each of three tests made with a tangential stress of 3 tons/sq.in.

However, an examination of the results shows that they are in general agreement with those obtained in the more usual form of Robertson test. Brittle cracks do not propagate if the temperature is too high or the stress too low. The results of the tests in which vessels were burst by internal pressure show that even at low temperatures, at which the steel ultimately fails in a brittle manner, failure occurred only after appreciable plastic deformation and at stresses well above the yield. This finding is not in agreement with the results of wide plate tests in which even stress-relieved plates failed at the yield stress. The probable explanation is that the artificial notch defect used in the vessel tests was appreciably less severe than that used in the wide plate tests cited earlier.[2,3] It is apparent then that at temperatures below T_R failures in stress-relieved pressure vessels may occur at the yield stress if very severe defects are present. But in those vessels where the design and construction is good and the level of inspection high, there may be a considerable additional margin of safety owing to the plastic deformation that precedes failure.

Conclusions

(1) In a modified form of Robertson test, pressure vessels exhibited the same type of behaviour as plate specimens. Brittle cracks would not propagate if the temperature was too high or the stress too low.

(2) At −60°C., the minimum stress for propagation was of the order of 3 tons/sq.in.

(3) A high average impact value is no guarantee against brittle fracture if the individual results are widely scattered.

(4) The minimum impact values (of longitudinal specimens) corresponding to the temperatures at which brittle cracks were arrested were about:

10–12 ft-lb for the Si-killed steel
33–37 ft-lb for the Al-killed steel.

(5) Stress-relieved mild steel pressure vessels containing sharp notch defects will yield and may deform considerably before they fracture, even at temperatures well below that at which the fracture becomes brittle.

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Welding RESEARCH

B.W.R.A. REPORT

Significance of Filler Metal Composition in Aluminium Alloy Welding

By J. G. Young, B.SC.

Aluminium alloy weld metal composition is controlled by parent material, filler alloy, dilution as influenced by joint preparation and welding technique, and element loss. Of these factors, filler alloy composition has special significance, for parent material composition is normally fixed, joint design is often dictated by material thickness and is only capable of variation within narrow limits, and element loss is a variable dependent on filler composition itself and to some extent on welding technique.

In welding a particular alloy, weld metal composition has a threefold significance. First, it is important in controlling weld cracking *behaviour (and heat-affected zone cracking to a minor extent). Second, the existence of weld metal of different composition to the parent plate may introduce* corrosion *problems; and finally, weld composition will have a profound effect on* mechanical properties *of the joint, whether it be in the as-welded or (where appropriate) in the post-weld heat treated condition. These three properties are all to be considered in assessing weldability.*

In this review, the significance of the filler metal is examined in general terms in relation to other factors which control weld composition, and alloy systems of current commercial interest are discussed.

Factors Controlling Weld Composition

Dilution and uniformity of composition

PERCENTAGE dilution is defined as the amount by which the filler metal is diluted by melted parent plate. Two independent investigations[1,2] have confirmed that, in single-pass arc welds, the weld metal is thoroughly mixed and is therefore of substantially uniform composition. This allows the weld composition to be calculated by simple proportion from filler and plate compositions if joint geometry is known, and is the basis of the well-known dilution nomogram[1] and formula:

$$C_w = C_f + \frac{D}{100}(C_P - C_f)$$

where D = percentage dilution
C_w = percentage element in weld
C_f = percentage element in filler
C_P = percentage element in parent metal.

The processes covered by these investigations included metal-arc (with flux coated electrodes) and argonarc but not inert-gas shielded metal-arc (sigma).

However, it is reasonable to infer that the results are equally applicable to the latter process of welding, and although no work has been published the examination of weld microstructures does provide confirmation.

Uniformity of composition does not extend to multi-run butt welds, and later runs, particularly in the centre of welds in thick plate, will not be diluted to the same extent as initial runs. For present purposes it is considered sufficient to adopt the dilution figures provided by Houldcroft,[1] and to assume uniformity of composition by taking an average figure for

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Table I

Dilution in different types of joint

Type of Joint	*Range of Dilution, %*
Fillets	25 (poor root fusion) to 40 (good fusion)
V Butts (multi-run)	40–55 (average figure for all runs)
V Butts (single run)	55–65
Close Butts	65 (thin plate) to 90 (thick plate)

multi-run welds. Typical dilution figures for different joint types are given in Table I.

Composition range of parent metal and filler alloy

Apart from the effect on final weld composition of the proportion of filler and parent metal incorporated in the weld, the composition range of any particular alloying element in both filler and parent metal is important in deciding probable final weld compositions.

A particular example may be cited in the use of NG2 filler wire for welding HP30 plate. The silicon content of NG2 is between 10 and 13%. The silicon in HP30 may be between 0·6 and 1·3%. For a single-run vee butt weld at 60% dilution, the Si in the weld may vary between 4·36 and 5·98%. Over the whole range of possible dilutions 25% (poor fillet) to 90% (close butt in thick plate) Si may vary between 1·54% and 10·08%.

The significance of composition range is expressed diagrammatically for a simple binary alloy in Fig. 1.

Element loss

No work has been carried out on the subject of element loss covering all processes, although several authors have given specific information on a particular element or process.

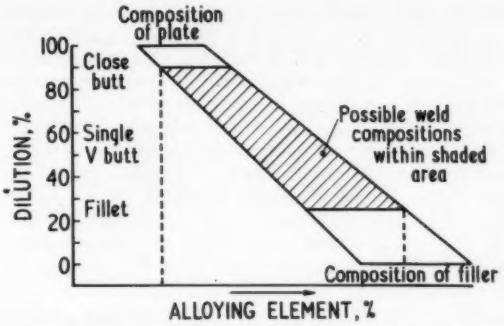
The A.D.A. Research Team[3] investigated magnesium and zinc losses in argonarc welding and magnesium losses in oxyacetylene welding. Losses of both elements were negligible in argonarc, and 1·5–4% of the total Mg content was lost in gas welding. West[4] quotes figures from several foreign sources and his information is summarised as follows:

Metal	*Process*	*Percentage Loss*
Magnesium	Oxyacetylene	8–16
Magnesium	Metal-arc	6–13
Silicon	Oxyacetylene	0– 3
Silicon	Metal-arc	11–40

This information was published before dilution and uniformity of composition was investigated and care must be taken in using these figures. Magnesium loss in metal-arc welding is more likely to be 30%. Hull[5] investigated Mg loss in sigma welding and quotes figures of 2–10%, and Tomlinson and Young[6] quote losses of from 0·25–0·50% Mg from NG6 wire (*i.e.*, 5–10%). Dumoulin[7] quotes a figure of 0·2% Mg loss from N6 type wire (*i.e.*, 4%). Recent B.W.R.A. work[8] on sigma welding shows that, with 6% zinc fillers, losses vary between 4 and 17% according to arc length, longer arcs giving higher losses. An average figure is 12%.

No information appears to have been published on losses of minor alloying elements, such as titanium and boron used as grain-refiners, but unpublished work by the present author suggests that whilst no titanium loss occurs in sigma welding, with boron the situation is somewhat doubtful.

The fact that when using the argon shielded welding processes element loss is usually ignored would seem to be justified by these figures. Loss of magnesium may be of marginal significance with regard to strength matching in certain cases, and its effect could be alleviated by slight modification to the composition range in the wire specification.



1—*Effect on weld composition of plate and filler composition range and of dilution, for a binary alloy*

Influence of Weld Composition on Weldability

Cracking

The importance of weld composition (and hence filler composition) in controlling weld cracking propensity in aluminium alloys is now widely understood, and whilst more elaborate theories explaining this behaviour may be forthcoming, sufficient is now known for all practical purposes.

Early aluminium welding relied upon the use of matching fillers where possible and, if cracking troubles were encountered, fillers selected on the basis of satisfactory production experience were employed. In 1944 the A.D.A. team at Birmingham University commenced a comprehensive and logical investigation into the factors influencing weld cracking, which has proved to be of fundamental significance.[3] Ring castings and restrained weld tests enabled cracking curves to be constructed for a wide range of binary and ternary alloys, and for some more complex high-strength alloys. Experiments by Yamaguchi Sahamoto and Yamamoto[9] gave very similar results. The composition figures for peak cracking in binary alloys in the two investigations are compared in Table II.

If such a peak occurs, the solution to the cracking problem is to choose filler compositions which will

Table II

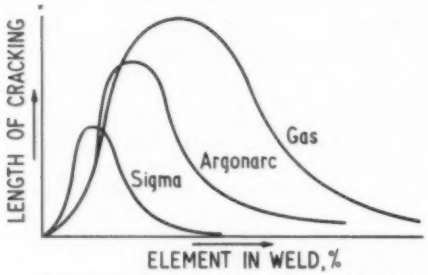
Comparison of cracking test data

	Element for Peak Cracking, %				
	Cu	*Si*	*Mg*	*Mg_2Si*	*Zn*
A.D.A.	3·0	0·6	4·0	1·0	20 (No peak)
Yamaguchi	1·0–2·0	0·25–0·5	4·0	—	8 (No peak)

result in a final weld composition as far from the peak as practicable. This usually means the selection of a filler more highly alloyed than the parent material.

This work on cracking was confined to oxyacetylene and argonarc welding. In sigma welding, the cooling rate is increased, and the author considers it probable that, as the cooling rate increases, the system is further from equilibrium and the peak diminishes in intensity and moves in the direction of lower alloy content. This hypothesis, presented in diagrammatic form in Fig. 2 may be worth confirming. Argonarc welding has been shown to give this result when compared with gas welding.[3]

Grain refinement has been said to reduce cracking propensity,[3,4] particularly in high-strength alloys, but the available evidence is meagre; and grain refinement



2—Possible effect of welding process on cracking behaviour

is not practised commercially in British filler wires. This aspect should receive further study, particularly in relation to modern processes and medium-strength 'weldable' alloys.

Corrosion

Little reliable information exists on the corrosion behaviour of welds in aluminium alloys, particularly in the context of variations in filler composition. Most of the published work (*e.g.*, Ref. 12) relates to oxyacetylene and metal-arc (flux coated electrode) welds, and results are usually given in terms of weight loss rather than in the more significant loss of mechanical properties.

The corrosion of pure aluminium welds in nitric acid is a popular topic.[13] Although the weld metal composition may be identical to that of the parent metal, a redistribution of Al–Fe–Si compounds in the cast metal makes the weld liable to corrosion. The problem is normally overcome by hammering and annealing the welds to break up grain-boundary films of these compounds. It may be possible to avoid hammering by the use of a purer grade of aluminium as the filler. British Standard Specification 3019 Part 1 permits the use of such fillers for argonarc welding but expresses no preference. Some controlled experiments would seem to be necessary.

The stress corrosion behaviour of aluminium-magnesium alloys is frequently mentioned in the literature, although such specific information as is available refers mainly to parent materials. Thus Jaeger[14] puts an upper limit of 4·7% Mg in aluminium-magnesium alloys for shipbuilding. Lancaster[15] says that the use of 5% Mg alloys for service at temperatures exceeding 65°C. must be avoided due to stress corrosion susceptibility. The same author says that stress corrosion of welds in alloys containing more than 6% Mg may occur even at room temperature. Dix[16] and his collaborators carried out stress corrosion tests on welds in three alloys of the 5% Mg type but did not refer to the filler materials employed. The same authors' work[16] on parent materials indicated that for service at temperatures in the range of 150°–350°F. (65°–175°C.) the plate should contain not more than 3% Mg.

There would appear to be a strong case for work on the stress corrosion behaviour of welded aluminium-magnesium alloys with specific attention to weld metal composition, which is of obvious significance.

Mechanical properties

The use of highly alloyed filler wires to overcome cracking problems in non-heat-treatable alloys frequently results in 'overmatching' with the general effect of an increase in strength of weld metal and often an increase in ductility of the joint, failure in the tensile test being transferred from weld metal to the heat-affected zone. Corrosion considerations apart, the provision of weld metal stronger than the heat-affected zone must be regarded as a desirable aim. Whether overmatching is of significance in fatigue remains to be investigated.

Minor alloying additions also play a significant part in determining weld metal strength, this being particularly true in the case of manganese and chromium in aluminium-magnesium alloys. Grain refinement is often said to be beneficial to strength but tests by the author on Al–5% Mg alloys failed to show any improvement in static tensile strength. The effect of weld metal grain size on fatigue of dressed welds is being investigated in a current B.W.R.A. programme.

In heat-treatable alloys the significance of weld metal composition in relation to strength is obvious in that some compositions will respond to natural or artificial ageing whereas others will not. Generally speaking, highly alloyed binary fillers will give a poor response to ageing treatments, particularly at low dilutions as in multi-run butt welds and fillet welds. It may thus be necessary to make minor alloying additions to the filler wire to improve ageing behaviour. Thus the ageing characteristics of welds in H15 made with Cusil 73[17] were markedly improved by the addition of 0·8% Mg to the filler wire.

Miscellaneous effects

It is considered possible that composition of filler wire (apart from gas content) may have an influence on porosity formation. It is certainly true that welds made with pure aluminium and 5% Si fillers tend to be more porous than those made with 5% Mg filler.

Table III

Grades of pure aluminium

	Composition, %				
Alloy	*Al*	*Fe*	*Si*	*Cu*	*Mn*
1	99·99	0·01 max.	0·01 max.	0·01 max.	—
1A	99·8	0·15 max.	0·15 max.	0·02 max.	—
1B	99·5	0·4 max.	0·3 max.	0·05 max.	0·05 max.
1C	99	0·7 max.	0·5 max.	0·10 max.	0·1 max.

Mantel and Wolff[18] claim that iron plays a significant part in pore formation in 5% Mg welds. It is difficult to imagine why this should be so. It is believed that in some German aluminium-magnesium alloys up to 0·5% Si is added to the parent metal to reduce edge-of-weld porosity in oxyacetylene welding. The mechanism of this effect is also obscure.

Fillers for Commercial Aluminium Materials

Pure aluminium

Four grades of pure aluminium are covered by British Standards. (Table III)

Normal practice is to use parent metal filler or material one grade more pure. The significance of this in relation to corrosion has already been discussed. It has been suggested[19] that 99·5% pure aluminium suffers from a slight hot cracking tendency compared with 99% material. In a limited number of Houldcroft tests[20] the author confirmed that this was so and that cracking could be reduced by using 1C filler wire for welding 1B. This is, of course, not applicable in cases where 99·5% parent metal has been chosen for its superior corrosion resistance.

Sixt[21] mentions the use of an aluminium-titanium alloy for welding 99·5% and 99·0% pure aluminium to give improved strength. Its effect on corrosion resistance is probably harmful.[14] Alloy NG3 (Al–1¼% Mn) has been used for improving weld strength in 1C aluminium.[15]

Table IV

Properties of welds in pure aluminium

Plate	*Filler*	*U.T.S., tons/sq.in.*	*Reference*
2S	2S	6	24
1A	1A, 1B or 1C	3–5	25
1B	1B or 1C	4–5	25
1C	1B or 1C	4–5	25
1100	1100	4·9–5·8	26
1B	Unspecified	4·9	27
1100	1100	6	28

British Standards for filler wire[22,23] stress the desirability that the percentage of silicon be less than that of iron and do not permit the addition of titanium in pure aluminium wires. Titanium is permitted in NG3 but NG3 is not specifically mentioned in the Standards for welding 1C parent material.

Among published properties are those given in Table IV. It will be noted that no comparisons between different fillers are available.

Aluminium-manganese alloy

The only aluminium-manganese alloy of interest in this country is the 1·0–1·5% Mn alloy N3. Cracking troubles are rare provided that attention is paid to the Fe/Si ratio (Unpublished Swedish work suggests 1·5:1).

Information on corrosion of welds is sparse but service experience has been generally satisfactory with parent metal filler.[29]

British Standards[30] permit the use of GIC (99·0% pure) filler in addition to NG3, although a slight loss in strength might be anticipated.

Published weld strengths are given in Table V which relates mainly to American practice where the use of commercial purity filler seems to be general.

Table V

Properties of welds in aluminium–1¼% manganese alloy

Plate	*Filler*	*Process*	*Condition*	*U.T.S., tons/sq.in.*	*Ref.*
3S–H12 3S–F	2S	Gas	Undressed dressed	7·2 6·5	31
3003	1100	Sigma	Not specified	7·1	28
NS3-0 ¾H	Not specified	Inert Gas	As welded	7·0	27
3S	2S	Inert Gas	Dressed and undressed	7·1	24
3003	1100	Sigma	Dressed and undressed	6·2–7·1	26
3S	S2	Argonarc	Dressed	6·8–7·1	32

Aluminium-magnesium alloys

As a result of their generally accepted good weldability there is more published information on these alloys than on any other group. The composition range of British alloys is given in Table VI.

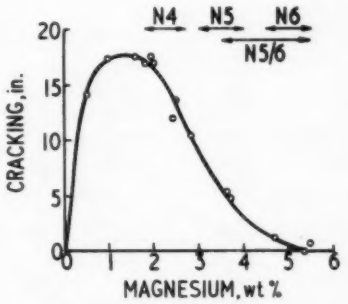
Table VI

Standard aluminium-magnesium alloys

Specification	*Forms*	*Composition, % Mg*	*Cu*	*Si*	*Fe*	*Mn*	*Cr*	*Ti*
N4	S,P,E,T,V,G.	1·8–2·7	0·10	0·6	0·7	0·5	0·5	0·2
N5	S,E,T,V,G.	3·0–4·0	0·10	0·6	0·7	1·0	0·5	0·2
N5/6	P	3·5–5·5	0·10	0·6	0·7	1·0	0·5	0·2
N6	S,E,T,V,G.	4·5–5·5	0·10	0·6	0·7	1·0	0·5	0·2
N7	S,E,T,G.	6·5–7·5	0·10	0·6	0·7	0·5	0·5	0·2

Single values are maxima

The composition for peak cracking in restrained weld tests determined by the A.D.A. team[3] and reported in the foregoing general section on cracking, requires some modification when related to commercial alloys owing to the presence of other elements. Work by Hollard[10] indicated that the addition of 0·4% Mn on its own does not alter the position of the peak, but that with 0·2% Fe and 0·2% Si, the peak is reduced to 1·5% Mg. Dowd[11] confirmed this figure in argonarc fillet weld cracking tests on commercial



3—*Effect of magnesium content of weld bead on cracking in commercial aluminium-magnesium alloys (Dowd)*

Table VII

Influence of fillers on weld composition in Al-Mg alloys

Parent Metal	*Filler Metal*	*Argonarc weld composition at 60% dilution, %*
N4 (2·25%)	*N5 (3·5%)	2·75
	*N6 (5%)	3·35
	N7 (7%)	4·15
N5 (3·5%)	N5 (3·5%)	3·5
	*N6 (5%)	4·1
	N7 (7%)	4·9
N5/6 (3·5–5·5%)	*N6 (5%)	4·1–5·3
	N7 (7%)	4·9–6·1
N6 (5%)	*N6 (5%)	5·0
	N7 (7%)	5·8

* Recommended in BS.3019, Part 1: 1958.

aluminium-magnesium alloys containing manganese and/or chromium and normal impurity levels of iron and silicon. Dowd's results, reproduced in Fig. 3, are generally regarded as the most useful for commercial alloys. The reason for the almost universal application of Al–5% Mg filler for welding alloys N4 to N6 will readily be appreciated. Somewhat strangely, however, the relevant British Standard recommendations permit the use of N5 filler (which may contain as little as 3% Mg) for welding N4 but not for N5. It might be reasonable to expect a higher magnesium filler to be used for the lower magnesium parent plate, as suggested by the figures in Table VII.

Table IX

High strength aluminium magnesium welds

Nominal Composition of Parent Alloy, %			*Filler Alloy*	*Minimum Properties (2 tests)*		
Mg	*Mn*	*Cr*		*0·1% Proof Stress on 2 in., tons/sq.in.*	*U.T.S., tons/sq.in.*	*Elong. on 2 in., %*
5	0·4	0	NG6	5·7	16·9	8·5
5	0·6	0·2	NG6	8·6	18·1	7
5	0·6	0·2	Parent Metal	10·0	19·2	8·5

If cracking were the only problem involved in formulating fillers for these alloys, a selection from the existing British Standards would satisfy all requirements. However, the problems of corrosion and strength remain to be considered and to some extent the requirements here may be conflicting. The absence of satisfactory corrosion data relevant to this discussion has already been noted.

Some recent data on strength of welds in aluminium-magnesium alloys is given in Table VIII.

There is a tendency to require the last ounce of strength in NP5/6 alloys, and at least one major concern is now marketing in Britain a 5083 type alloy with high Mg, Mn, and Cr contents. It is unlikely that

Table VIII

Properties of welds in Al-Mg alloys (chiefly American)

Alloy Type	*Plate*	*Filler*	*Weld Analysis, %*	*Process*	*Condition*	*U.T.S., tons/sq.in.*	*Ref.*
N4	*5052	5052	2·5 Mg 0·25 Cr†	Sigma	Dressed and Undressed	11·0–12·5	26
	*5052	5356	3·3 Mg+Mn+Cr†	,,	Not stated	12·5	28
	*N4–0	Not specified	Not known	Inert Gas	As welded	12·5	27
	NS4–0	N4, N5, N6	—	,,	Not stated	11	39
N4/N5	3 in. 5154–F	5154	2·85 Mg 0·05 Mn 0·23 Cr	Sigma	Undressed	14·7–16·7	33
N5	*5154	5154	3·5 Mg 0·25 Cr†	,,	Dressed and Undressed	13·4–14·7	26
	½ in. 5154–0	5154	3·43 Mg+Mn+Cr	,,	{Dressed {Undressed	15·5–16·0} 16·2–16·6}	34
	½ in. 5154–0	5356	4·11 Mg+Mn+Cr	,,	{Dressed {Undressed	15·5–16·3} 16·4–16·5}	34
	*5154	5154	3·5 Mg 0·25 Cr†	,,	Not stated	14·7	28
	*N5–0	Not specified	Not known	Inert Gas	As welded	14·8	27
	Ns5–0	N5	—	Inert Gas	Not stated	13·5	39
	,,	N6	—	,,	,,	14	39
N5/6	*NP5/6–M	Not specified	Not known	Inert Gas	As welded	17·0	27
	NP5/6–0&M	N6	—	Inert Gas	Not stated	16	39
N6	3 in. 5056–1	5056	4·6 Mg 0·10 Mn 0·10 Cr	Sigma	Undressed	17·4–18·7	33
	*5056	5356	Not known	,,	Not stated	17	28
	*5356	5356	5·0 Mg 0·12 Mn 0·12 Cr 0·13 Ti	,,	Dressed and Undressed	17–18·7	26
	*5356	5356	5·0 Mg 0·12 Mn 0·12 Cr 0·13 Ti†	,,	Not stated	17·8	28
	*5456	5356	5·25 Mg 0·8 Mn 0·1 Cr†	,,	Dressed and Undressed	18·7–20·5	26
	¼ in. 5083–0	5083	4·61 Mg 0·7 Mn 0·16 Cr	,,	{Dressed {Undressed	18·1} 19·2}	35
	*5083	5356	Not known	,,	Not stated	19	28
	¼ in. 5086–0	5083	4·34 Mg 0·57 Mn 0·17 Cr	,,	{Dressed {Undressed	15·8} 17·5}	35
	½ in. 5086–0	5356	4·57 Mg+Mn+Cr	,,	{Dressed {Undressed	16·8–18·0} 15·8–18·4}	34
	*5086	5356	Not known	,,	Not stated	16·5	28
	NS6–0	N6	—	Inert Gas	,,	16	39
	*N6–0	Not specified	Not known	Inert Gas	As welded	17·8	27

* Range of Thicknesses † Estimated

the optimum weld properties will be achieved with this parent metal unless a specially formulated filler is used. Such a filler could be supplied to NG6 although ideally some adjustment to the composition range might be required to cater for element loss and to ensure over-matching.

Some figures obtained by the author for close square butt argonarc welds in $\frac{1}{8}$ in. thick annealed 5% Mg alloy sheet are presented in Table IX.

The excellent properties of the Cr-containing alloy as well as the significance of filler composition in a high dilution weld are brought out in this comparison.

Aluminium-magnesium-silicon alloys

The hot cracking susceptibility of these alloys is well-known and has been the subject of extensive investigations at B.W.R.A.[36] and elsewhere.[2] It is generally accepted that Si-rich fillers should be used with all four of the British alloys (H 9, 19, 20 and 30) to overcome cracking troubles, although 5% Mg (NG6) is sometimes recommended. Edge-of-weld cracking has been noted with the latter filler however.[20] When Si-rich fillers are employed, the minimum silicon content for ensuring freedom from cracking is 3·5%. In practice a minimum figure of 2·5% is acceptable. In terms of dilution, this means that, with alloy H30, the maximum permissible dilution is 80% with NG2 (eutectic silicon) filler and 50% with NG21 (5% Si filler). It has been suggested that a filler intermediate in composition between N21 and N2 would be useful but it will be evident from Fig. 4 that the gap is insufficiently wide to need closing. In fact, from the cracking viewpoint, there would seem to be little merit in using NG21, since NG2 can cope with the whole range of dilutions encountered in normal practice. When post-weld anodising is necessary the risk of cracking is accepted and fillers are chosen which give the best colour match (*e.g.*, NG4).

Information on corrosion behaviour is once again meagre, but it is believed that no particular problems have arisen with Si-bearing fillers. With Mg-bearing fillers it is possible that the weld metal would be anodic to the plate and would therefore be liable to corrosion owing to the small anode/cathode ratio.

Table X

Strength of welds in Al-Mg-Si alloys

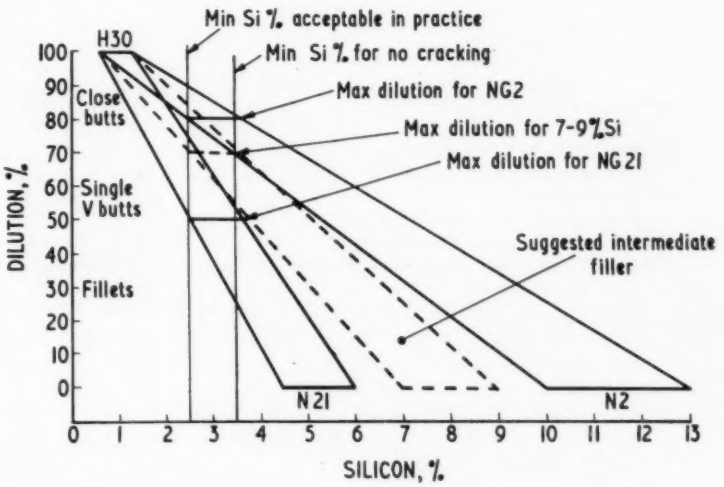
Parent Metal	*Filler*	*Condition*	*U.T.S., tons/sq.in.*	*Reference*
H10	NG6	As welded	12·05	37
	NG7	,,	12	
	H10	,,	11·6	
	NG21	,,	11·7	
6061–T6	4043	As welded;	12·05	28
		fully H.T.	19·2	
H30WP	Not specified	As welded;	12	27
		fully H.T.	19·2	
61S–T6	43S	As welded	13·8–14·9	38
61S–T6	43S	As welded;	11·6	24
		fully H.T.	19·2	
6061–T6	4043	As welded;	12	26
		fully H.T.	19·2	
6061–T6	5154	As welded;	12·8	
		fully H.T.	16·5	

With heat-treatable alloys, the influence of filler metal composition on joint strength is somewhat difficult to assess owing to the effect of variations in welding technique and post-weld heat treatment. With the magnesium-silicide age-hardening alloys welded in the fully heat-treated condition, overmatching of the heat-affected zone (which is softened) is readily obtained with all fillers, as demonstrated by Handforth.[37] With post-weld heat treatment it is generally not possible to overmatch the parent material, and a low ductility fracture in the weld metal occurs in the tensile test. Hull and Adams[36] showed that the addition of 1·25% Mg improved the response to heat treatment of Al–7·5% Si cast rods.

A selection of published information on weld properties is given in Table X.

Aluminium-zinc-magnesium alloys

Interest is rapidly growing in the medium-strength copper-free alloys typified by Unidal and Superalumag T35. It is generally recognised that they are



4—Weld composition for H 30 alloy and various fillers

Table XI

Recommended filler materials for wrought aluminium alloys

Material	*BS.1470–1477*	*Filler Alloy*	*BS.2901*
99·99% pure	1	99·9% pure	G1
99·8% pure	1A	99·8% pure	G1A
99·5% pure	1B	99·5% pure	G1B
99% pure	1C	99% pure	G1C
Al–1¼% Mn	N3	Al–1¼% Mn	NG3
Al–2½% Mg	N4	Al–5% Mg	NG6
Al–3½% Mg	N5	Al–5% Mg	NG6
Al–Mg–Mn	N5/6	Al–5% Mg	NG6
Al–5% Mg	N6	Al–5% Mg	NG6
Al–Mg–Si	{H9, H19 {H20, H30}	{Al–5% Si {Al–10% Si	NG21 NG2
Al–Zn–Mg (medium strength)	—	{Al–7% Mg {Al–5% Mg	NG7 NG6

Note—In certain circumstances alternative fillers are preferred and the greater risk of cracking is accepted (*see* text).

somewhat crack sensitive but that they may be welded with Mg-bearing fillers such as NG6 or NG7. An extensive investigation into the weldability of these alloys is currently in progress at B.W.R.A.[8]

Information on corrosion behaviour is sparse but it is understood that investigations are planned.

The attractive property of this type of alloy is the high as-welded proof stress, which may attain 14 tons/sq.in. in the naturally aged condition or 19 tons/sq.in. in the artificially aged condition. Filler composition is likely to be of significance in butt welds in thick plate where dilution is low. Such aspects are covered in the B.W.R.A. programme.

Conclusions

In the field of weld cracking behaviour, suitable fillers are available for all commercial alloys of current interest and these are given in Table XI. The general lack of corrosion and stress corrosion data is apparent and the effect on corrosion behaviour of variations in filler composition has not received sufficient attention. Static strength of welds attainable with standard fillers is usually adequate, although with the tendency to push the properties of aluminium-magnesium alloys to the limit, overmatching may be difficult to achieve with existing filler alloys.

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Heat-Affected Zone Cracking of Two Austenitic Steels during Welding

By R. N. Younger, M.A.,
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Cracking in the heat-affected zone has been investigated in 18Cr/12Ni/1Nb and 18Cr/8Ni type steels by means of a simple welding test. The results indicate that in both steels shallow cracking can occur in the heat-affected zone during welding.

The high-temperature ductility during a rapid heating and cooling cycle has been assessed by torsion testing. These tests have shown that in both steels there is a range of temperature immediately below the melting point where the ductility is very low.

It is suggested that cracking in the heat-affected zone is initiated at these temperatures in locally melted regions close to the fusion line, and that the cracks then propagate into material at a lower temperature where they are arrested.

CONSIDERABLE difficulty has been experienced recently in the fabrication of thick sections of austenitic steels for power generation plant. The material which has been most frequently used is A.I.S.I. Type 347, 18Cr/12Ni/1Nb steel. In this steel premature failures have frequently occurred owing to cracking in the heat-affected zones of welds.

In a preliminary examination of this problem[1] it has been shown that cracking in the heat-affected zone occurs in two distinct stages: during welding and during subsequent heat treatment. The conditions under which the two forms occur are quite different, and it is with the first of them—cracking during welding—that this report principally deals.

Previous work on the occurrence and theories of cracking has been reviewed in a literature survey by Borland and Younger.[2] Pellini and his associates[3] have found that cracking may occur during welding, and have suggested a mechanism by which hot tearing of the base metal occurs owing to the liquation of low-melting-point segregates. Nippes and his associates[4] believe that the heat-affected zone is damaged when it is cycled to a high peak temperature, and they have obtained experimental evidence to show that loss in ductility occurs at temperatures approaching the solidus.

The present work was undertaken to obtain a better understanding of the factors causing cracking during welding and of the effect of this cracking on subsequent behaviour during heat treatment.

Experimental Techniques

The BWRA cracking test

To study the problem under controlled conditions, a test weldment was designed which provided great rigidity during welding. Details of the test are shown in Fig. 1. Where single run conditions were being investigated, a plane prepared surface was substituted for the ½ in. deep preparation shown in Fig. 1. The metal-arc welding procedure was standard, depositing each run in two 180° segments, followed by a pause of sufficient time to allow the weldment to cool to room temperature.

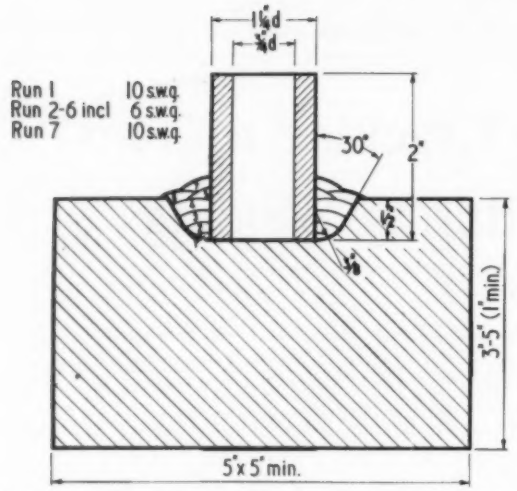
After removal of slag, the heat-affected zone was examined by means of a binocular microscope with a ×20 magnification. Suspected regions were then examined by sectioning transverse to the welding direction.

Torsion testing during rapid thermal cycles

To determine the ductility of materials during a rapid heating and cooling cycle, apparatus was designed for torsion testing specimens under these conditions. Hollow cylindrical specimens, with a wall thickness of 0·03 in., were heated by h.f. induction to a preset peak temperature, followed by quenching in an argon stream. The maximum rate of heating was about 100°C./sec between 500° and 1400°C. The specimens were rapidly torsion tested to failure at predetermined temperatures, either while heating or while cooling. A value of the ductility was obtained by measuring the angle of twist before failure, recorded on an oscillograph. The rate of twisting was 160 rev/min, and the maximum value of ductility recorded was one revolution (360° twist), thus giving a maximum duration of testing of 0·375 sec. Measurements of temperature

Report B5/10/61 of the British Welding Research Association, circulated to members in July 1961.

Dr. Baker and Mr. Borland are Principal Research Officers, and Mr. Younger a Research Officer, with the Association.



1—*BWRA welding test and details of metal-arc welding procedure*

2—*Hot tearing in H.A.Z. of 18Cr/12Ni/1Nb type steel during welding. Etched oxalic acid* ×200

Table I

Composition of steels tested

	Composition, %							
Steel No.	*C*	*S*	*P*	*Si*	*Mn*	*Cr*	*Ni*	*Nb*
Steel 1	0·085	0·005	0·029	0·64	1·48	17·27	12·20	0·87
Steel 2	0·06	0·020	0·020	0·33	1·14	18·36	13·28	0·83
Steel 3	0·07	0·025	0·025	0·60	0·90	18·78	8·18	—
Steel 4	0·08	0·020	0·023	0·51	1·17	18·16	8·57	—

Table II

Composition of electrodes used

	Composition, %								
Electrode Type	*C*	*Si*	*Mn*	*Cr*	*Ni*	*Nb*	*Cu*	*Co*	*W*
Electrode *B*	0·09	0·46	1·2	18·8	9·2	0·7	2·0	—	—
Electrode *D*	—	—	—	33	—	—	—	55	6

were made by means of a Pt/Pt.Rh thermocouple welded to the inside of the specimen.

Experimental Results

Weld tests

The compositions of the steels tested and of the electrodes used are given in Tables I and II.

18Cr/12Ni/1Nb type steel (steel 1). After the deposition of a single run of electrode *B* on this steel, intermittent cracking in the heat-affected zone was observed around the entire circumference of the weld. The cracking was 3–4 grains deep and ran 1–2 grains from the fusion line. A transverse section through a typical crack is shown in Fig. 2, and a section parallel to the surface in Fig. 3. This section also shows minor surface cracks whose origin is uncertain.

A further test was carried out on a section of the same steel which had been subjected to a solution treatment of 3 hr at 1330°C. This treatment had increased the grain size from A.S.T.M. 6 to A.S.T.M. 0. With the increased grain size, cracks were observed at many points below the surface where grain boundaries intersected the fusion boundary, in addition to cracking at the surface. In all cases the cracks were quite short and were never observed to exceed about 0·03 in. in length. A typical sub-surface crack is shown in Fig. 4.

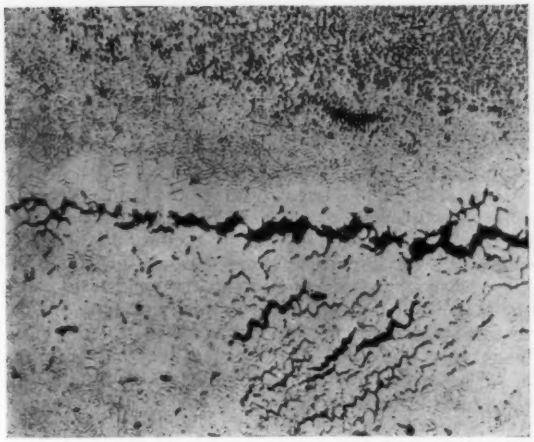
In certain non-ferrous systems[5] cracking adjacent to the fusion boundary can be eliminated by welding with an electrode with a low solidus temperature, and it was decided to use the same approach in this investigation. If hot tearing takes place at regions of local liquation it is reasonable to suppose that it can be eliminated by ensuring that the weld metal solidifies after the liquified regions of the base plate, since contraction stresses to open the tears have to be transmitted largely through the weld metal itself. This is in accordance with the ideas of Pellini *et al* [3] who postulated a hot tearing mechanism to explain cracking during welding of similar steels. Accordingly, weld tests of the 18Cr/12Ni/1Nb steel were made using electrode *D* (Table II). This electrode is a hard-facing electrode which, compared with electrode *B*, has much greater hot strength but a solidus temperature 50°–100°C. lower. No cracks were found after welding with the low solidus electrode. The solidus temperature of the two electrodes was determined by thermal analysis and the results are shown in Table III.

18Cr/8Ni steel. Welding tests have been made on 18Cr/8Ni steel (steel 3, Table I) using a single run of electrode *B* weld metal. After welding, some cracking in the heat-affected zone was observed. Where sectioning through these isolated areas of cracking was found

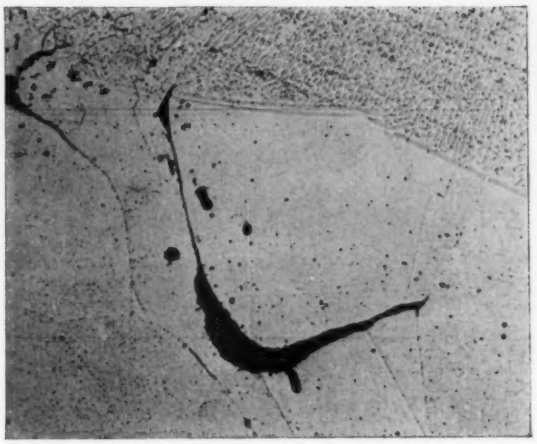
Table III

Approximate solidus temperatures of electrodes used

Electrode Type	*Solidus Temperature, °C.*
Electrode *B*	1420
Electrode *D*	1350



3—*Surface of H.A.Z. of 18Cr/12Ni/1Nb type steel after welding Etched oxalic acid* ×100



4—*Hot tearing in H.A.Z. of 18Cr/12Ni/1Nb type steel welded after solution treatment at 1330°C. Etched oxalic acid* ×200

to be possible the depth of cracking was restricted to 0·005 in.

Torsion testing during rapid thermal cycles

Since cracking was thought to occur at a temperature close to the melting temperature, a programme of high-temperature torsion testing was initiated. Testing was carried out at high strain rates during a rapid heating and cooling cycle, and the ductility was recorded.

An 18Cr/12Ni/1Nb type steel (steel 2, Table I) was tested using a peak temperature of 1310°C. The results are shown in Fig. 5. The ductility of this material, under these conditions, began to fall rapidly at a temperature of about 1250°C., and reached a very low value at 1300°C. On cooling the behaviour was similar.

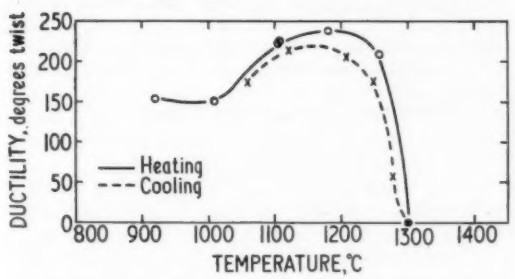
An 18Cr/8Ni type steel (steel 4, Table I) was tested using a peak temperature of 1380°C. The results are shown in Fig. 6. It can be seen that the ductility of this material remained high up to a temperature of 1350°C., and thereafter fell rapidly. Considerable ductility was regained on cooling to 1310°C.

Discussion

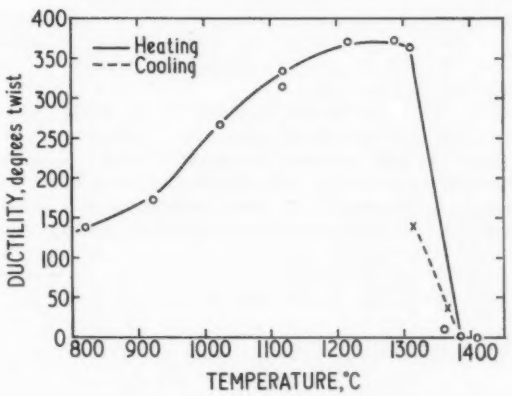
It has been shown that in 18Cr/12Ni/1Nb type steel cracking in the heat-affected zone can occur during welding. The extent of this cracking is usually very limited but nevertheless it is important for two reasons. Firstly, cracks formed during welding can act as points of initiation for a more serious form of cracking which may develop during subsequent heat treatment.[1] This is probably due to a stress concentration effect. Secondly, it has been shown that solution treatment of the base metal at high temperatures before welding results in a much greater degree of susceptibility to cracking during welding. Thus the problem may become important in castings and forgings of large grain size.

Mechanism of cracking

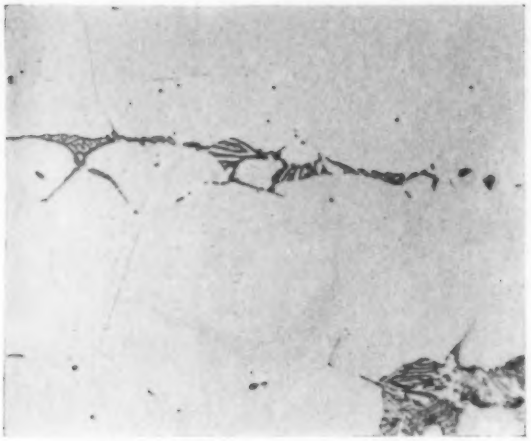
From the evidence obtained in the present investigation it is clear that cracking occurs at very high temperatures. This has been shown by the welding experiments, where the formation of cracks seems to depend predominantly on the relative solidus temperatures of the weld and base metal. The low solidus electrode did not cause cracking in spite of its high hot strength. This is what would be expected if cracking could occur only at temperatures above that



5—*Torsion ductility of 18Cr/12Ni/1Nb type steel*



6—*Torsion ductility of 18Cr/8Ni type steel*



7—Grain boundary melting in the region of primary NbC particles in an 18Cr/12Ni/1Nb steel specimen

at which the weld metal had acquired strength due to solidification.

This hypothesis is further supported by the results of the torsion testing programme. The complete loss of ductility of the 18Cr/12Ni/1Nb steel at temperatures above 1300°C. has already been reported by Nippes *et al*[4] and by Pellini.[3] The cause of the loss of ductility is not fully understood but the temperature at which it appears coincides with the occurrence of grain boundary melting. This melting is observed in regions close to the primary NbC particles present in the original structure as elongated stringers (Fig. 7).

In the case of weld heat-affected zones, whilst cracks apparently initiate immediately adjacent to the fusion boundary, they often run too far from the fusion line to be correlated directly with the obvious melting observed in regions of massive NbC particles. However, it is quite possible that cracks could initiate at locally liquefied regions. Having initiated, they might possibly propagate along films of liquid too thin to observe in the light microscope. However, dendritic NbC has never been observed at distances greater than about 1 grain diameter from the fusion boundary, and the cracks often propagate to distances further from the boundary than this. The explanation for this behaviour may be that, having nucleated, the cracks may be self-propagating for short distances before being blunted owing to the increasing ductility of the material at their tips.

It is also possible that cracks having nucleated at high temperature might propagate at lower temperatures. No direct evidence for or against this possibility was obtained in the investigation. However, if the cracks do propagate at lower temperatures, it is not apparently the result of strain-induced precipitation as is the case when the steel is reheated. No strain-induced precipitates have ever been observed in the immediate vicinity of the cracks after welding alone.

In the case of the unstabilised 18Cr/8Ni steel, cracking during welding also occurred but to a markedly smaller extent than in the Nb steel. This difference in behaviour was also reflected in the results of the torsion tests, the Nb steel showing zero ductility over a range extending to about 100°C. below the bulk solidus, whilst in the unstabilised steel zero ductility was shown in a range extending to only about 40°C. below the bulk solidus. There was no direct microscopical evidence of liquation in the weld tests using the light microscope, but it was apparent in the torsion tests after testing in the nil-ductility region. Thus with this steel also it is feasible that cracking could have been nucleated in liquated regions adjacent to the fusion boundary.

Conclusions

(1) The problem of cracking in the heat-affected zone of 18Cr/12Ni/1Nb steel and 18Cr/8Ni steel has been investigated using a simple welding test. Cracks up to 0·03 in. deep in the 18Cr/12Ni/1Nb steel and up to 0·005 in. deep in the 18Cr/8Ni steel were observed in the heat-affected zone after welding immediately adjacent to the fusion line.

(2) Increasing the grain size of the Nb-bearing steel by a high-temperature treatment increased the amount of cracking on the surface and also gave rise to cracking beneath the surface in the H.A.Z. immediately adjacent to the fusion boundary.

(3) The use of a low solidus weld metal prevented cracking, although the solidified weld metal had a comparatively high hot strength.

(4) Torsion tests carried out at high temperatures during both heating and cooling show that in the Nb steel there is a temperature range of about 100°C. immediately below the melting point where the ductility was too small to be detected. The unstabilised steel also showed a nil-ductility range but of about 40°C.

(5) It is suggested that cracks initiate during welding in locally melted regions immediately adjacent to the fusion boundary and propagate into material of a lower temperature and higher ductility, where they are quickly arrested.

REFERENCES

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2. J. C. Borland and R. N. Younger: *Brit. Welding J.*, 1960, vol. 7, pp. 22–59.
3. W. S. Pellini *et al.*: *Welding J.*, 1956, vol. 35, pp. 9*s*–17*s*.
4. E. F. Nippes *et al.*: Welding Research Council Bulletin Series No. 33, 1957.
5. P. T. Houldcroft: Private communication.

B.W.R.A. REPORT

Heat-Affected Zone Cracking in Welded Austenitic Steels During Heat Treatment

By R. N. Younger, M.A., *and R. G. Baker*, M.A., PH.D.

Heat-affected zone cracking during post-weld heat treatment has been investigated in a wide range of austenitic steels by means of a simple welding test. Metallographic investigation has been carried out using direct carbon extraction replica and thin foil techniques in the electron microscope.

The results indicate that extensive intercrystalline cracking may occur during heat treatment and that susceptibility to this depends markedly on chemical composition. Cracking is due to the formation of strain-induced precipitates within the grains, leading to enhanced stress concentration at the grain boundaries. Some methods of approach to the problem are considered in the light of the possible factors affecting precipitation.

WHEN austenitic steels are welded in thick sections two quite distinct forms of cracking may occur in the heat-affected zone.[1] During welding, small cracks may be formed in the heat-affected zone immediately adjacent to the fusion boundary. An investigation into this type of cracking is reported elsewhere.[2] A much more serious form of cracking can develop when the joints are reheated after welding, either during service or during stress relief. This form of cracking has caused a great deal of trouble in practice, particularly in the super-heater systems of power stations.[3,4] This paper concerns an investigation into the occurrence and cause of cracking during heat treatment in a range of commercial austenitic steels.

Experimental Technique

B.W.R.A. welding test

In the B.W.R.A. welding test, devised by Borland *et al.*,[5] a block of the material to be tested (of minimum dimensions 5 in. × 5 in. × 3 in.) and a tube of the same material with an outside diameter of 1¼ in. were used. The joint geometry and welding procedure were chosen to simulate as closely as possible a stub pipe to header joint. This was one type of joint where cracking was known to occur in service.[3] A diagram of the test assembly is shown in Fig. 1 of Report B5/10/61*.

Welding was carried out by the metal-arc process. During the course of testing it was observed that the degree of cracking during heat treatment varied in susceptible steels, increasing with an increase in the hot strength of the electrode used. Thus it was possible to alter the severity of the test by welding each material with electrodes of differing compositions (Table I). The 0·5% proof stress of the weld metals at 750°C. was measured in hot tensile tests and was found to increase in the order A < B < C < D.

After welding, the test weld was heated in a muffle furnace at 100°C./hr to the required temperature, held there for the heat-treatment period with an accuracy of ±10°C., and furnace cooled. Where heat-treatment temperatures above 750°C. were being investigated a rate of heating of 1200°C./hr was used. Experiments had shown that specimens heated at this rate to 1050°C. were entirely free of cracks. Thus it was reasonable to assume that any cracking found after heat treatment at 850° and 950°C. took place isothermally at these temperatures and not during the course of heating.

After heat treatment the weldments were examined for signs of cracking at a magnification of × 20, and metallographic sections were taken through any suspect areas.

Metallographic examination

Transverse sections of the heat-affected zone were ground, abraded, electro polished, and etched in a mixture of hydrochloric, nitric, and sulphuric acids. Carbon extraction replicas were then taken using the technique developed by Smith and Nutting[6] and adapted for use with austenitic steels by Arrowsmith.[10] The replicas were examined in a Siemens Elmiskop I electron microscope, the selected area electron diffraction technique being used where possible to identify precipitated phases.

* See p. 576 of this issue.

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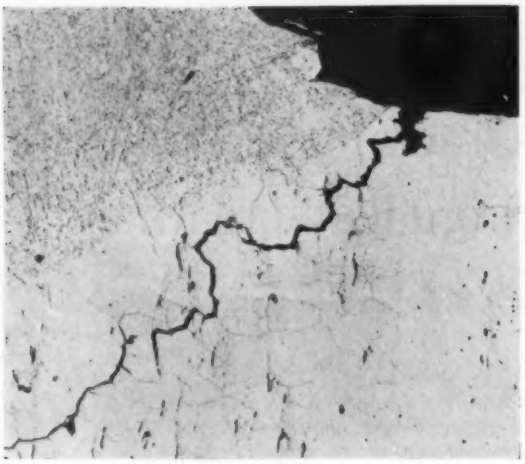


1—*Cracking in H.A.Z. of 18Cr/12Ni/1Nb type steel after 100 hr at 750°C. Etched oxalic acid* ×50

Table I

Nominal composition of electrodes used

Electrode	*Composition, %*									
	C	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*Nb*	*Cu*	*Co*	*W*
A	0·07	2·0	0·6	17·5	8·5	1·9	—	—	—	—
B	0·09	1·2	0·46	18·8	9·2	—	0·7	2	—	—
C	0·23	2·05	0·79	16·2	17·5	2·5	2·1	—	7·0	—
D	—	—	—	33	—	—	—	—	55	6

Results of Welding Tests

18Cr/12Ni/1Nb steel

Effect of reheating temperature—On reheating test welds of 18Cr/12Ni/1Nb steel at 750°C. for times greater than 1 hr, extensive intercrystalline cracks propagated from the root of hot tears formed during welding. A typical crack is shown in Fig. 1. The cracking was confined to the heat-affected zone and was of considerable extent, sometimes reaching depths of ½ in. or more.

The onset of this form of cracking was found to depend on the time and temperature of reheating. The results of tests carried out at 550°, 650° and 750°C. are shown in Table II. The period of time before the onset of cracking decreased with an increase in reheating temperature. Specimens which were heated rapidly to 850°C. and 950°C. and maintained at these temperatures were found to be cracked. Specimens heated at similar rates to 1050°C. and maintained at this temperature were uncracked.

Effect of pre-heat—Weld tests have been made on 18Cr/12Ni/1Nb steel with preheat temperatures of 650°, 750°, 850°, and 900°C. The weld test was used in its most severe form by welding with electrode *D* (Table I). The weld assembly was heated in a vertical muffle furnace to the required temperature, the top of the furnace was removed, and welding begun. The processes of welding and slag removal continued until the temperature of the assembly fell to a minimum of 25°C. below the required temperature. When this occurred the top of the furnace was replaced and the weldment was reheated to the required temperature.

After weld tests of this sort, carried out at 550°, 650° and 750°C. the heat-affected zone was subsequently found to be cracked. After tests at 850° and 900°C. the heat-affected zone was found to be uncracked.

Weld testing of further compositions

A wide range of austenitic materials has been weld tested followed by heat treatment for 100 hr at 750°C. The results of these tests are given in Tables III and IV and the analysis of the materials tested in Table V. The materials can be considered in two groups.

Group I—This group consisted of five steels with a base composition of 17–18% Cr, 8–12% Ni. Three of the five steels contained one of the carbide forming elements Ti, Nb, Mo; the strongest carbide former in the remaining two steels was Cr. The Nb-bearing steel was found to be the most susceptible to cracking. The steel containing molybdenum was found to be the only steel which could not be made to crack even under the severe conditions provided by the use of electrode *D*.

Group II—This group consisted of four steels all of which contained Nb but which varied widely in their content of other alloying elements. All of these steels were found to be susceptible to cracking during heat treatment, but none was found to be as susceptible as the steel stabilised with Nb alone.

Metallography of the Heat-Affected Zone of Welded Specimens

The following results were obtained from weldments after heat treatment for 100 hr at 750°C. Carbon extraction replicas were taken from a region within three grain diameters of the fusion line of the weld.

18Cr/12Ni/1Nb—(Cracked)

Electron micrographs of the heat-affected zone of this steel confirmed the existence of large (0·2 μ) $M_{23}C_6$ particles at the grain boundaries (Fig. 2*a*). However, in addition to these, there was a copious precipitate of NbC dispersed throughout the grain. The individual precipitate particles were very fine (100–150Å dia.). A traverse across the heat-affected zone showed that the precipitated particles were most numerous within a few grains of the fusion line.

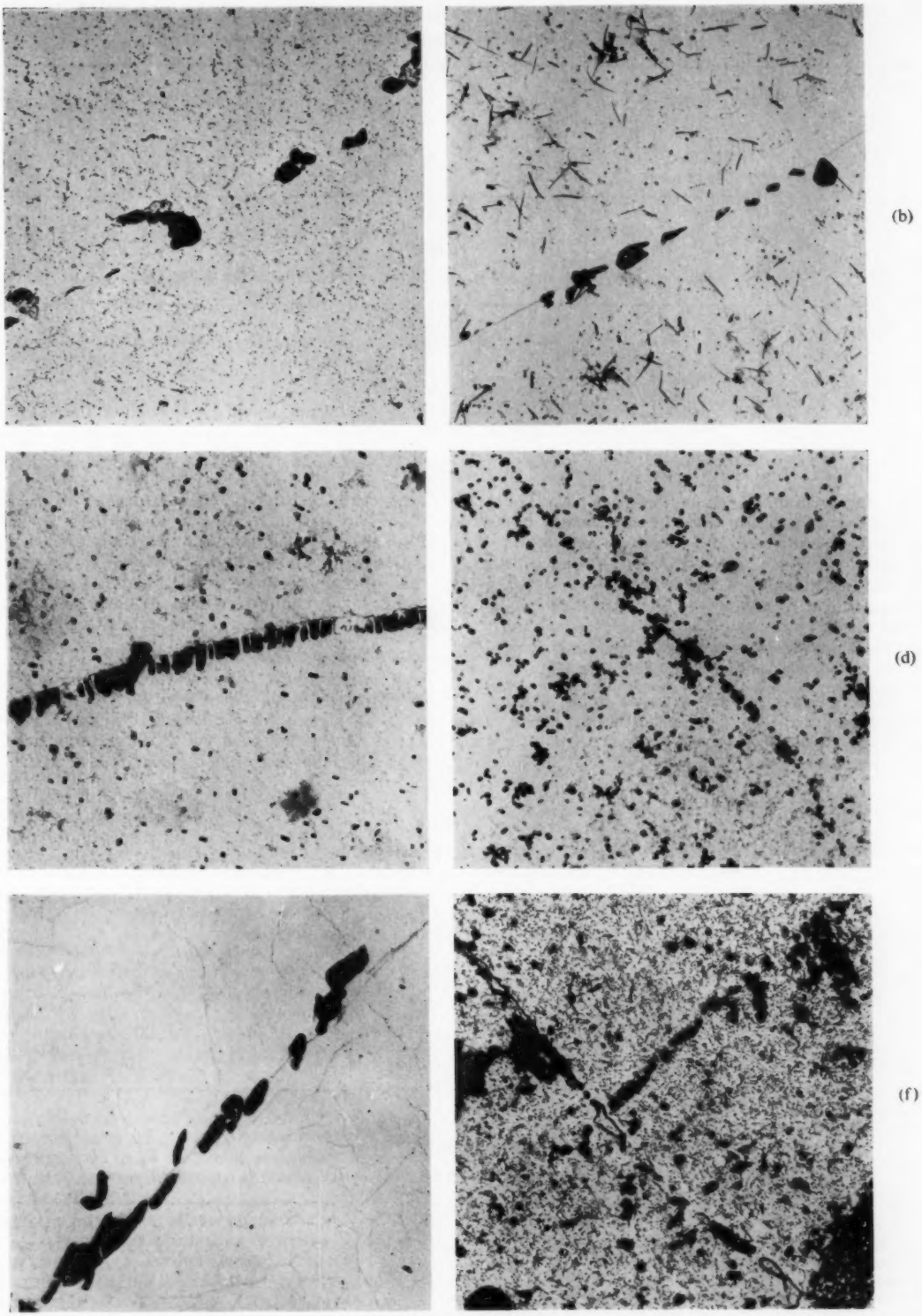
18Cr/10Ni/0·5Ti—(Cracked)

Examination of the heat-affected zone of 18Cr/10 Ni/0·5Ti steel showed a similar structure (Fig. 2*b*).

Table II

Effect of time and temperature on heat treatment cracking of 18Cr/12Ni/1Nb type steel

Temp. °C.	*Heat Treatment Time, hr*				
—	0·1	1	3	70	1400
750	nil	cracked	cracked	cracked	cracked
650	nil	nil	nil	cracked	cracked
550	nil	nil	nil	nil	cracked



2—*Heat-affected zones of various steels after 100 hr at 750° C. Carbon extraction replicas* ×20,000
(a) *18Cr/12Ni/1Nb, electrode B;* (b) *18Cr/10Ni/0·5Ti, electrode B;* (c) *18Cr/8Ni, electrode B;*
(d) *18Cr/8Ni, electrode D;* (e) *16Cr/10Ni/2Mo, electrode B;* (f) *17Cr/18Ni/Co.Nb.Mo (0·24 C), electrode B*

Table III

Results of welding tests on group I steels after heat treatment for 100 hr 750°C.

Electrode Type	*Material Type*				
	18Cr/12Ni/1Nb	*18Cr/10Ni/0·5Ti*	*18Cr/8Ni*	*18Cr/8Ni.L.C.*	*16Cr/10Ni/2Mo*
A	Cracked	Nil	Nil	Nil	—
B	Cracked	Nil*	Nil	Cracked	Nil
C	Cracked	Cracked	Cracked	Cracked	—
D	Cracked	Cracked	Cracked	Cracked	Nil

Table IV

Results of welding tests on group II steels after heat treatment for 100 hr 750°C.

Electrode Type	*Material Type*			
	16Cr/10Ni/Nb.Mo	*16Cr/10Ni/Nb.Mo.(L.C.)*	*16Cr/10Ni/6Mn/Nb.Mo.B*	*17Cr/18Ni/Nb.Co.Mo*
A	Nil	Nil	Nil	Nil
B	Cracked	Nil	Cracked	Nil
C	Cracked	Cracked	Cracked	Cracked
D	Cracked	Cracked	Cracked	Cracked

The fine precipitate was in this case TiC. The grain boundary denudation and the appearance of needle shaped precipitates in this specimen were found to be phenomena which developed only during protracted ageing treatments. They were not observed after treatments of 3 hr or less (Fig. 5) at 750°C.

18Cr/8Ni— (i) Welded with electrode *B* (uncracked)
(ii) Welded with electrode *D* (cracked)

These specimens were selected in an attempt to determine the effect of variations in weld metal strength on heat-affected-zone microstructure. Only the specimen welded with electrode *D* cracked during heat treatment. Typical microstructures from each of these two specimens are shown in Figs. 2*c* and 2*d*. Both specimens contained a fine precipitate within the grains which was identified as $M_{23}C_6$. However, in the case of the specimen welded with the electrode of higher hot strength (electrode *D*), there was a marked increase in the number of precipitated particles.

16Cr/10Ni/2Mo—(Uncracked)

A micrograph of the heat-affected zone in 16Cr/10 Ni/2Mo steel is shown in Fig. 2*e*. This was the only steel which could not be made to crack in the welding test. The structure consisted of large grain boundary $M_{23}C_6$ particles but, in complete contrast to the other

Table V

Analyses of materials tested

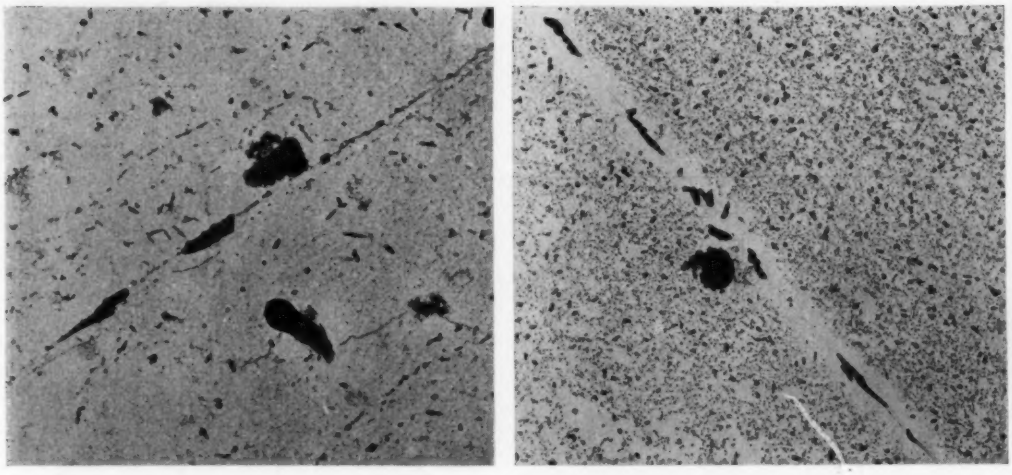
Material Type	*Composition, %*													
	C	*S*	*P*	*Si*	*Mn*	*Cr*	*Ni*	*Nb*	*Mo*	*Ti*	*Co*	*V*	*B*	N_2
18Cr/12Ni/1Nb	0·085	0·005	0·029	0·64	1·48	17·27	12·20	0·87	0·1	—	—	—	—	0·042
18Cr/10Ni/0·5Ti	0·09	0·002	0·027	0·66	1·28	18·16	10·94	—	0·45	0·69	—	—	—	N.A.
18Cr/8Ni*	0·07	0·025	0·025	0·60	0·90	18·78	8·18	—	0·22	—	—	—	—	0·038
18Cr/8Ni(L.C.)*	0·023	0·007	0·009	0·51	0·80	18·08	11·20	—	—	—	—	—	—	N.A.
16Cr/10Ni/2Mo	0·04	0·016	0·018	0·22	1·59	16·56	10·54	—	2·25	—	—	—	—	N.A.
16Cr/10Ni/Nb.Mo	0·08	0·003	0·020	0·51	1·17	16·57	11·52	0·97	1·41	0·02	—	—	—	0·031
16Cr/10Ni/Nb.Mo.(L.C.)*	0·04	0·009	0·011	0·35	1·07	16·48	11·58	0·41	1·64	—	—	—	—	N.A.
16Cr/10Ni/Nb.Mo.B	0·12	0·013	0·022	0·44	5·72	15·92	9·58	0·90	1·08	0·13	—	0·22	0·005	0·039
17Cr/18Ni/Nb.Co.Mo	0·24	0·006	0·018	0·48	3·00	17·12	18·09	1·64	2·27	—	5·66	—	—	N.A.

* Cast analyses N.A. = Not analysed

Table VI

Relative specific volumes of phases precipitated from group I steels relative to an austenitic matrix

Material Type	*18Cr/12Ni/1Nb*	*18Cr/10Ni/0·5Ti*	*18Cr/8Ni*	*16Cr/10Ni/2Mo*
Predominant carbide	NbC	TiC	$M_{23}C_6$	Nil
Specific volume of carbide relative to austenite	1·91	1·76	1·15	—
Susceptibility to cracking during heat treatment (c.f. Table III)	High (A, B, C, D)	Medium (B, C, D)	Low (C, D)	Nil (—)



(a) *Thermally cycled and heated 100 hr at 750°C.*, (b) *Thermally cycled, plastically deformed, and heated* 100 *hr at 750°C.*

3—*18Cr/12Ni/1Nb type steel specimens. Carbon extraction replicas* ×20,000

steels, no fine precipitate was observed within the grains.

Group II steels—(All cracked)

Examination has been made of the microstructure of weld test specimens of all the steels listed in Group II (Table IV). This examination showed that in all cases there was a copious intragranular precipitate of NbC in the heat-affected zone. In the case of the high carbon 17Cr/18Ni/Co.Nb.Mo steel, two different forms of intragranular precipitate were found to coexist. The microstructure of this steel is shown in Fig. 2*f*. The fine precipitate dispersed within the grains is NbC; the coarser precipitate, with clearly defined crystallographic faces, is $M_{23}C_6$.

Metallography of Simulated Heat-Affected Zone Microstructures

Effect of plastic strain

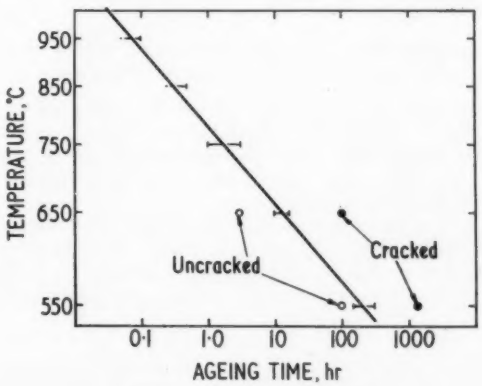
It was considered important to determine whether the microstructure of the heat-affected zone could be produced by heat treatment alone. For this purpose an apparatus was constructed which would subject small metallographic specimens to a thermal cycle similar to that experienced by the heat-affected zone near the fusion zone of the weld. High-frequency heating and argon quenching were used to give heating and cooling rates which corresponded very closely to these measured in 1½ in. thick stainless steel plate.[7] Specimens heat treated in this way were then aged for 100 hr at 750°C.

To investigate the effect of plastic deformation, which is known to occur in the heat-affected zone during welding, a further series of specimens was subjected to the same thermal cycle but deformed 10% before ageing.

The resulting microstructures are shown in Figs. 3a and 3*b*. In the undeformed specimen there were very few precipitated particles within the grains; in this respect the microstructure differed markedly from that of the heat-affected zone (Fig. 2*a*). The structure of the deformed specimen, on the other hand, was similar to that of the heat-affected zone but contained even more precipitated particles. It is thought that the greater deformation of the thermal cycled specimen would account for the finer dispersion of precipitation observed in Fig. 3*b*. Subsequent work has shown that an elongation of 3% before ageing produces a microstructure almost identical to that observed in the heat-affected zone of a weld test specimen.

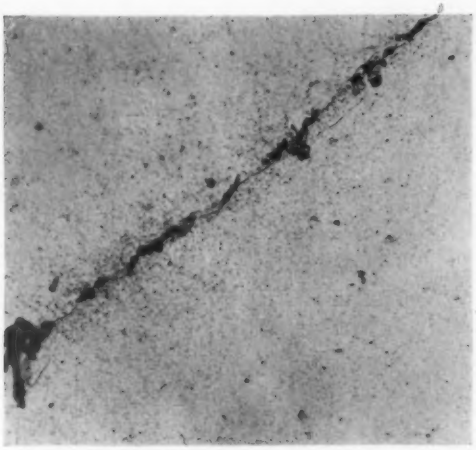
Ageing characteristics of specimens after thermal cycling and deformation

18Cr/12Ni/1Nb steel—Intragranular precipitation was observed in this steel after ageing at all temperatures



Scales: Ordinate – reciprocal °K
Abscissa – logarithmic time scale

4—*Relationship between temperature and time of ageing needed before:* (1) *Precipitates could be extracted from metallographic specimens (full line);* (2) *cracking was detected in weld test (circle points)*



5—*18Cr/10Ni/0·5Ti steel specimen, thermally cycled, plastically deformed, and heated 0·1 hr at 750°C. Carbon extraction replica* ×20,000

between 550° and 1050°C. The logarithm of the minimum ageing time before intragranular carbides could be extracted has been plotted against reciprocal of ageing temperature (°K) in Fig. 4. The relationship is linear and indicates an activation energy of 36–38 kcal/g.mol which does not vary appreciably over the temperature range investigated.

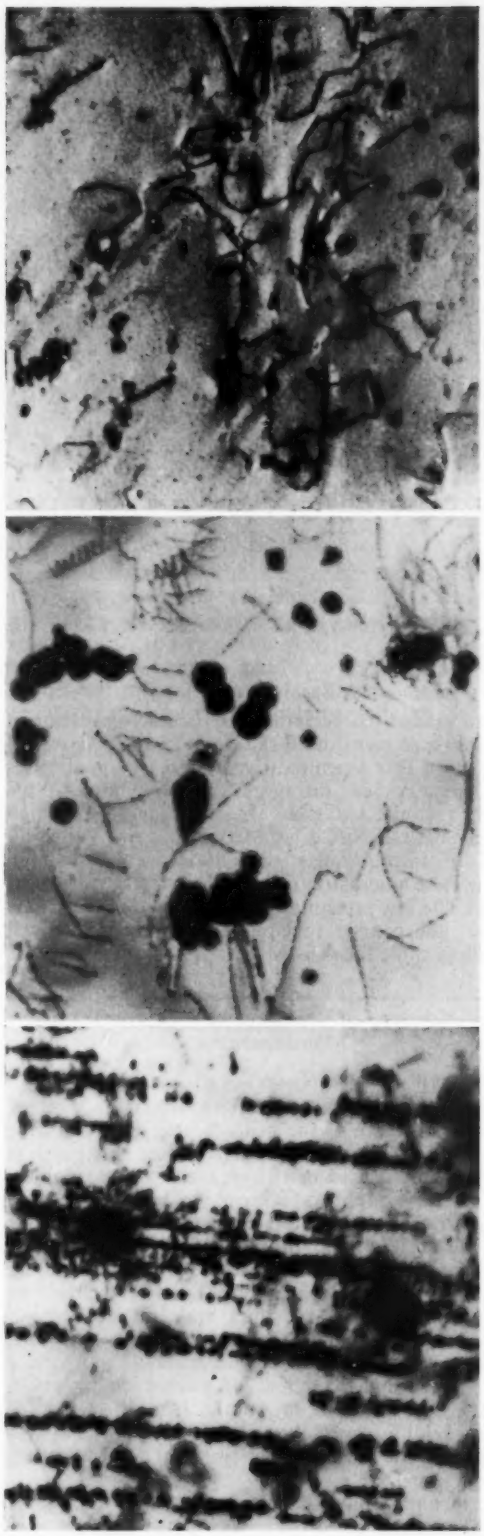
Remaining steels—The ageing characteristics of the remaining steels (with the exception of 16Cr/10Ni/2Mo steel) were generally similar to those of the 18Cr/12Ni/1Nb steel. At all temperatures, however, the ageing time necessary before intragranular precipitates could be extracted was similar to or less than that required for the 18Cr/12Ni/1Nb steel. This effect was particularly marked in the case of the Ti-bearing steel, where precipitates were extracted from specimens aged for only 6 min at 750°C. A typical micrograph of this specimen is shown in Fig. 5.

No intragranular precipitation was observed in 16Cr/10Ni/2Mo steel after ageing at 550°C. for 3000 hr or at 650°–1050°C. for shorter times.

Examination of Thin Foils of 18Cr/12Ni/1Nb Steel in Transmission in the Electron Microscope

In an attempt to examine the mode of precipitation of NbC in plastically deformed specimens, thin foils of 18Cr/12Ni/1Nb steel have been examined in transmission in the electron microscope. Some preliminary results have been obtained.[8]

Specimens, rolled to 0·015 in. thick, were solution treated at 1300°C, deformed 3% in tension, and aged for various times at 650°C. Thin foils were then prepared by an electro-polishing technique.[9] After ageing



(a)

(b)

(c)

6—*Precipitation of NbC on dislocations during the ageing of 18Cr/12Ni/1Nb steel after solution treatment and 3% deformation. The specimens are thin foils examined directly in the microscope:* (a) *Aged for 1 hr at 650°C.—no precipitates are yet visible on the dislocations.* ×40,000; (b) *aged for 16 hr at 650°C.—precipitates have formed on the dislocations.* ×40,000; (c) *aged for 100 hr at 650°C.—showing precipitation on dislocation loops.* ×80,000

for 1 hr at 650°C. the foils contained many dislocations with no signs of precipitation upon them (Fig. 6a). After ageing for 16 hr at 650°C., however, NbC was precipitated on the dislocations (Fig. 6*b*). Precipitation was apparently continuous along the line of the dislocations with 'bumps' at intervals of 200–400Å. This mode of precipitation has been previously reported by Arrowsmith and Nutting[10] in a study of precipitation in a Nb-bearing austenitic steel using extraction replica techniques. The presence of the precipitate was also evident in diffraction patterns taken from selected areas of the thin foils. In addition to precipitation of this type, parallel rows of NbC particles were observed in certain regions of the austenite (Fig. 6*c*). In both these cases there was a unique orientation relationship between the precipitate and the matrix.[8] This can be expressed as:

$$(100)_{NbC} // (100)_{\gamma}$$
$$[001]_{NbC} // [001]_{\gamma}$$

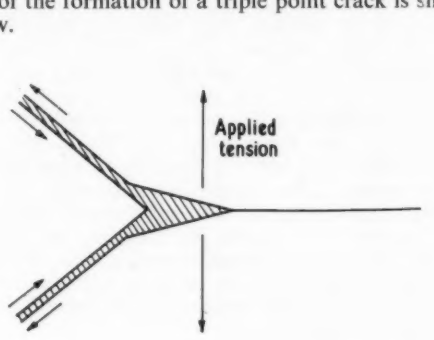
or in other words the precipitate and matrix unit cells are identically oriented.

Discussion

Relationship between intragranular precipitation and cracking

From the results of welding tests, involving heat treatments over a range of temperatures, it is evident that heat-affected-zone cracking during reheating is always accompanied by the precipitation of a fine dispersion of carbide throughout the grains. This form of precipitation has already been shown to have a deleterious effect on high-temperature ductility.[11,12] It has been established that plastic deformation is necessary to provide this fine dispersion, the dislocations generated during deformation acting as sites upon which carbides can subsequently nucleate.

Residual stress is present in a specimen after welding and, on reheating, creep relaxation will occur by the combined processes of grain boundary sliding and grain deformation. Grain boundary sliding must result in the formation of high stress concentrations at points in the boundary unless relaxation can occur by plastic deformation of the grains. Therefore if sufficient deformation of the grains under these conditions is not possible, the stress concentration at the grain boundaries will increase and may become high enough for cracks to form. It is suggested that heat-affected-zone cracking occurs when strain-induced precipitation stiffens the grain to this degree. A schematic illustration of the formation of a triple point crack is shown below.



If this mechanism of cracking is correct any factors which affect grain boundary sliding would be expected to influence cracking; anything which hindered grain boundary sliding would be expected to be beneficial and vice versa. It is difficult, however, to discuss the possible effects of grain boundary precipitated phases and segregates because of the lack of unambiguous experimental data. It might be expected, for instance, that precipitates at the boundaries would pin them and prevent sliding from taking place, but in the present investigation cracking has been observed both in steels where grain boundary precipitation was very sparse (16Cr/10Ni/Nb.Mo) and in those in which it was very copious (17Cr/18Ni/Co.Mo.Nb).

It thus seems reasonable to conclude that in heat-affected-zone cracking strain-induced precipitation within the grains is the primary controlling factor. It is of course possible that changes in grain boundary conditions may have an important second order effect, and in conditions other than those studied they might have a much greater relative effect. It is also possible that in certain marginal cases the state of the grain boundaries may be a determining factor in whether or not cracking occurs. However, as the dominant effect on the ductility appears to derive from strain-induced precipitation, further discussion will be confined largely to the factors affecting this process and its effect on grain stiffening.

Effect of chemical composition on precipitate nucleation

The carbides which have so far been found to precipitate in an intragranular dispersion in the steels investigated are NbC, TiC, and $M_{23}C_6$. These carbides are all face-centred cubic and thus have the same type of structure as the parent austenite. No evidence has yet been obtained of the precipitation of hexagonal molybdenum carbide (Mo_2C, MoC) within the grains at this level of supersaturation, although Mo may substitute to a very small extent (7 at.%) in $M_{23}C_6$. In 18Cr/8Ni steels, the strongest carbide former is Cr. When high carbon steels (0·4%C) of this type are solution treated and aged, Widmanstatten precipitation of $M_{23}C_6$ occurs throughout the grains.[10] When the carbon content is reduced to the level of the steels used in this investigation (0·08% and 0·023%) the degree of supersaturation is reduced, and plastic deformation is necessary before appreciable precipitation can occur within the grains on ageing. Thin foil studies in the electron microscope show that dislocations can act as sites for the nucleation of $M_{23}C_6$ as they do in the case of NbC in Nb-bearing steels.

When Mo is added to these steels, the carbon activity may be further reduced, yet in a steel containing 0·1%C and 2½%Mo, intragranular precipitates of $M_{23}C_6$ are still formed on ageing after plastic deformation.[13] However, when the Mo content is retained at 2½% and the carbon level further reduced to 0·04%, as in the Mo-steel investigated, precipitation of $M_{23}C_6$ is completely suppressed.

It is suggested that in this case the carbon activity is so low that precipitation cannot occur within the grains even on dislocations. The Mo:C ratio in this steel is 55:1 by weight, an atomic ratio of 7:1.

The situation is generally similar in the Nb-bearing steels. Niobium has a high affinity for carbon, and in a steel containing 0·08%C and 1%Nb intragranular

precipitation of $M_{23}C_6$ is suppressed and NbC is subsequently formed. If the carbon level is then increased to 0·24% and the niobium to only 1·6% the carbon activity is raised, and $M_{23}C_6$ is formed followed by NbC. This has been observed in the 17Cr/18Ni/Co.Mo.Nb steel (Fig. 2*f*).

Solute elements may have other effects besides their direct role in the formation of a precipitate and an effect upon the carbon activity. The formation of a precipitate on a dislocation is likely to depend upon the structure of the dislocation. This will be largely determined by the stacking fault energy. It is well known that dislocations in austenite can dissociate by reactions such as:

$$\frac{a}{2}[\bar{1}10] \rightarrow \frac{a}{6}[\bar{2}11] + \frac{a}{6}[\bar{1}2\bar{1}]$$

The partial dislocations repel each other and move apart leaving a ribbon of stacking fault between them. This can be regarded as a thin layer of high energy material. Equilibrium is reached when the interaction energy of the partial dislocations is balanced by the total energy of the stacking fault. Suzuki[14] has considered segregation of solutes to stacking faults and has shown that in general an interaction can occur with an effective alteration of the stacking fault energy and hence of the dislocation structure. This may well have a dual effect upon precipitate nucleation since not only is the structure of the site modified, but also, owing to segregation at the stacking fault, the diffusion path to the nucleating site may be modified.

Effect of the nature of the precipitate on cracking

The precise stage of the precipitation process at which cracking occurs is difficult to determine, but there is no evidence that cracking takes place at a stage prior to that at which strain-induced precipitates can be extracted.

The results of the thin foil electron microscopy programme have shown that precipitates of NbC in the steels investigated are identically orientated with the austenite matrix, so that there is an interfacial mismatch of about 20%. It would thus seem unlikely that the precipitate can remain coherent for very long during growth and it is almost certain that it would have lost full coherency at the stage at which cracking is found to occur. However, the specific volume of carbide phases is very large relative to the austenite matrix and this would be expected to play an important part both in the growth of the precipitate and in its effect on grain strength as suggested by Arrowsmith and Nutting.[10] In the case of NbC, which has the greatest difference in specific volume, hardness testing has been used to follow the precipitation process. Room temperature tests carried out on specimens of 18Cr/12Ni/1Nb steel after 1–5% deformation have shown that the hardness increases steadily with ageing and is still increasing after treatments of 100 hr at 650°C. After this treatment, the precipitates of NbC are 100–150Å in diameter.

During the growth of a precipitate which has a large specific volume relative to the matrix, vacancies must diffuse to the precipitate; otherwise large hydrostatic compressional stresses would be generated which would prevent further growth. This has several implications:[10]

(1) The growth of such precipitates may be controlled by the ease with which vacancies can be supplied to them. If this is so the rate of growth will tend to be lower in the case of precipitates of high relative specific volume. It has been observed in the present investigation that the rate of growth is lowest in the steel containing Nb alone, which is in accordance with this hypothesis.

(2) If growing precipitates, with large specific volumes, act as efficient vacancy sinks, it follows that the creep rate will be decreased. Creep deformation of grains is generally supposed to involve climb, and the process of climb requires the diffusion of vacancies to jogs.

Thus one might suppose that such systems would show comparatively low creep ductility during the process of precipitate growth. One might further deduce that creep ductility would decrease with an increase in the relative specific volume of the precipitate. This is in accordance with the behaviour of steels containing Cr, Ti, and Nb respectively as shown in Table 6. As the misfit volume increases in the order of $M_{23}C_6 < TiC < NbC$ the cracking susceptibility also increases.

The lattice misfit can also be altered by changing the lattice parameter of either the matrix austenite or the precipitate by the addition of elements which go into solid solution in either of them. The results of the welding tests show that in the case of the 'Group II' Nb-bearing steels, alloying the austenite with Mo, Co, and Mn invariably reduces the degree of susceptibility until, in the case of the 17Cr/18Ni/Co.Mo.Nb steel, the susceptibility is low. All these elements would be expected to reduce the relative mismatch whether they dissolve preferentially in carbide or in austenite.

Prevention of cracking

There are two approaches to the problem of avoiding heat-affected-zone cracking during reheating. One is to reduce the deformation in the heat-affected zone to a minimum. This may be achieved by decreasing the hot strength of the weld metal, by good joint design, and by the removal of stress concentrators such as hot tears.

The second general approach is to prevent the formation of a microstructure with a sufficiently high susceptibility to cause cracking in a given type of joint. One way of doing this is to reheat rapidly to a high temperature after welding. This prevents creep relaxation from taking place at temperatures where low ductility microstructures are formed. It is also possible to avoid cracking by welding at high preheats (850° to 900°C.).

Alternatively one may seek to control cracking by altering the composition of the steel. It has been shown that strain-induced precipitation can be completely suppressed by this means as in the case of the Mo-bearing steel. Thus, provided that the general mechanical and corrosion properties of such a steel render it suitable for a particular application, the problem can be entirely avoided. However, it is difficult to believe that this could ever be a completely general solution to the problem. It is certainly probable that austenitic steels designed in the immediate future for good resistance to creep and oxidation are going to be liable to strain-induced precipitation. Indeed, the presence of such precipitates may be essential to develop the required creep behaviour. Thus it is important to understand how the ductility in such systems may be improved by changes in composition with the minimum impairment of the creep strength. A possible approach to this problem, by changing the relative specific volumes of precipitate and matrix, has been discussed in the foregoing sections but much more work needs to be done before soundly based predictions can be made.

Summary and Conclusions

(1) Heat-affected zone cracking in thick sections of austenitic steels during reheating after welding constitutes a potentially very serious practical problem.

(2) The problem has been investigated by means of a simple welding test. Extensive intercrystalline cracking occurred in the specimens on reheating in the temperature range 550°–950°C. The induction period for cracking decreased with increasing temperature.

(3) A wide range of austenitic steels has been investigated. All these steels, with the single exception of a 16Cr/10Ni/2¼Mo/0·04C steel, showed some degree of susceptibility to heat treatment cracking. An 18Cr/12Ni/1Nb steel showed the greatest susceptibility, whilst Nb-bearing steels containing other alloying elements were significantly less susceptible. Titanium-bearing and unstabilised 18Cr/8Ni steels were also found to be susceptible.

(4) When cracking occurred during reheating it was always accompanied by the formation of a fine intragranular precipitate. In steels containing Nb this was predominantly NbC, in steels containing Ti it was TiC, and in unstabilised steels it was $M_{23}C_6$.

The steel containing Mo, which showed no tendency to heat treatment cracking, contained no intragranular precipitate in the heat-affected zone.

(5) Increasing the hot strength of the weld metal increased the extent of cracking and produced finer and more numerous intragranular precipitates.

(6) The fine intragranular precipitate was strain-induced. Larger amounts of plastic deformation resulted in finer and more numerous precipitated particles. Examination of thin foils in the electron microscope showed that nucleation of strain-induced precipitates could take place directly on dislocations. In the case of NbC nucleated in this way, a unique orientation relationship existed between the precipitate and austenite lattice:

$$(100)_{NbC} // (100)\ \gamma$$
$$[001]_{NbC} // [001]\ \gamma$$

(7) Cracking is due to stiffening of the grains by the strain-induced precipitate particles. This causes an increase in stress concentration at the grain boundaries which may result in the formation of intercrystalline cracks.

(8) Cracking may be avioded in the following ways:

(*a*) Rapid heating after welding to a sufficiently high reheating temperature
(*b*) Preheating to a temperature in excess of about 850°C.
(*c*) The use of a weld metal of lower hot deformation resistance combined with adequate ductility
(*d*) The use of a less susceptible steel.

(9) Minor changes in chemical composition can result in a change in susceptibility to cracking. It has been suggested that this may be the result of:

(*a*) Changes in carbon activity
(*b*) Changes in suitability of nucleation sites
(*c*) Changes in the relative specific volumes of the precipitate and of the austenite unit cells.

The relative importance of these factors is being investigated.

Acknowledgments

The authors would like to thank the members of the B.W.R.A. Committee on the Welding of Cr–Ni austenitic steels for their advice and help, and in particular Mr. J. I. Morley and Dr. K. J. Irvine for arranging the supply of steels used in the investigation.

They are also very grateful to Mr. H. F. Tremlett, Professor J. Nutting, and Mr. D. Haddrill for helpful discussions and to their colleagues at B.W.R.A.; in particular Mr. C. Humphries who carried out much of the experimental work.

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NEWS and Announcements

News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

MEETINGS

Extraordinary General Meeting

An Extraordinary General Meeting of the Institute will be held at 54 Princes Gate, on 3rd January, 1962 at 5.30 p.m. The meeting is being called to approve amendments to the Articles of Association and to approve an increase in the rates of subscription of individual members.

Christmas Lecture

The Annual Lecture to Young People will be presented at 11.0 a.m. on Thursday, 4th January, 1962, by Mr. John Strong (Past-President). His subject will be "*Joining the Modern Way*". The Lecture will be given at the offices of the Institute, 54 Princes Gate, Exhibition Road, London S.W.7. Tickets are required, and these are obtainable from the Secretary.

Welding in Shipbuilding

The Annual Meeting of the Institute this year took the form of a Symposium on Welding in Shipbuilding, believed to be the first full-scale symposium devoted to this subject anywhere in the world.

The meeting was jointly organised with the four leading British shipbuilding institutions (Royal Institution of Naval Architects, Institute of Marine Engineers, North East Coast Institution of Engineers and Shipbuilders, and the Institution of Engineers and Shipbuilders in Scotland) and was held in the Memorial Hall of the Institute of Marine Engineers from 30th October to 3rd November.

The Symposium was opened by Vice Admiral Hughes Hallett, Parliamentary Secretary of the Ministry of Transport, who welcomed the many visitors from overseas: Sweden, Japan, the Netherlands, France, Poland, Italy, Malta, Norway, Australia, Denmark, Finland, Germany, Spain, Switzerland, and the U.S.A.

Seven technical sessions were held for the presentation of 34 papers, 14 from the United Kingdom, and 20 from seven other countries. All sessions were well-attended, and the discussions were lively and fruitful.

There were three receptions during the meeting; the first was by the invitation of the Chairman and Committee of Lloyd's Register of Shipping, and was held in their offices in Fenchurch Street. The second was held at the Dorchester Hotel by the invitation of the Shipbuilding Conference, and the third by the invitation of the President and Council of the Institute of Welding. These informal occasions provided ample opportunity for the overseas visitors to renew old friendships and to make new acquaintances.

Halfway through the 5-day meeting, the Institute of Welding held its Annual Dinner at the Connaught Rooms, and those enrolled for the Symposium were invited to attend. The Principal Guest was the Rt. Hon. Lord Carrington, K.C.M.G., M.C., First Lord of the Admiralty, and he proposed the toast of the Institute with lively humour. The reply was made by the President, Mr. H. West. The toast to the Guests was proposed by Mr. L. Redshaw, Vice-President, and the response was given by Mr. F. I. Geddes, M.B.E., Chamber of Shipping.

The Reception by the Institute on Thursday, 2nd November, was preceded by the Presidential Address by Mr. H. West. His subject was the Institute itself; its growth and its activities in the educational field. The Address will be published in the January 1962 issue of *B.W.J.*

The papers presented at the Symposium were made available in preprint form and will be republished with the discussion in 1962 as the "Proceedings of the Symposium on Welding in Shipbuilding".

Cover Illustration

A working model of S.S. *Oriana*, showing the influence of stabilisers, was one of the displays at the Conversazione held in conjunction with the Institute's Reception.

NEWS OF MEMBERS

Mr. R. C. Thomson, who for the past 7½ years has been Welding Engineer with G. A. Harvey & Co. (London) Ltd., has now joined the Syntilla Manufacturing Co. Ltd., of Dunstable, as Company Welding Engineer.

Mr. F. H. Mead has become a Partner in Oscar Faber & Partners, Consulting Engineers.

Dr. Robert Lakner, Ph.D., has been appointed Managing Director of Oerlikon Electrodes (Great Britain) Ltd., and **Mr. H. O. Willrich,** Dip. Ing., and **Mr. F. W. Pinkstone** have been appointed Directors.

Obituary

The Council regrets to record the death of the following member:

Mr. W. Cottam (N.E. Tees-side, Member, 1933).

ELECTION OF MEMBERS

The following elections have been made effective from the dates indicated:

Member

W. E. Moorhouse (Herts) —28.9.61

Associate Members

P. A. Beresford (Doncaster); *R. W. Bevan (Swansea); E. A. Ilori (London); N. Lockwood (Hants); L. Naylor (Lancs); †D. F. O'Dwyer (Wolverhampton); D. P. C. Price (Newcastle upon Tyne); A. G. Senior (London); S. E. Warren (London) —28.9.61

Companion

A. E. Farnworth (Lancs) —28.9.61

Graduate

C. F. W. Jones (Shropshire)—28.9.61

Associates

D. Brooks (Lancs); J. W. Ogden (Manchester); A. Rimmington (Eire); T. J. Spring (Glam) —28.9.61

* Transfer from Associate
† Transfer from Companion

PUBLICATIONS

There are a few copies of the preprints of the 34 papers presented at the Joint Symposium last month available for distribution. Graduates of the Institute are offered the opportunity to buy copies for £1 each. Graduates should write to the Secretary of the Institute enclosing a remittance.

SCHOOL OF WELDING TECHNOLOGY

The following programme of courses has been arranged for the Winter Session 1961–62:

D.17/1—Advanced Course 13th–17th Nov.
D.3/3—Design for welding in general engineering 4th–8th Dec.
D.33/1—CO_2 Arc Welding 15th–18th Jan.
D.35—Design of welded pipework 29th–30th Jan.
D.5/4—Non-destructive weld examination 12th–16th Feb.
D.34—Welding metallurgy 26th–28th Feb.
D.18/2—Metal spraying 12th–14th Mar.
D.38—Hard facing 15th–16th Mar.

Evening Courses

The School will also be offering the following evening courses in the industrial centres shown:

Birmingham: Design for welding in steel construction Nov. 1961–Mar. 1962
Bristol: Design for welding in steel construction Jan–Mar. 1962
Leeds: Design for welding in steel construction Jan–Mar. 1962
Manchester: Detail design of welded structured steelwork Jan–Mar. 1962

The syllabus of the Birmingham Course is as follows:

Lecture 1—16th Nov.—*The Concept of Good Design* by F. C. Ashford.
Lecture 2—24th Nov.—*Arc Welding Processes and their relation to Design* by J. A. Lucey.
Lecture 3—1st Dec.—*Principles of Material Selection for Welding* by N. T. Burgess.
Lecture 4—8th Dec.—*The Welded Joint* by H. B. Merriman.
Lecture 5—15th Dec.—*Analysis and Design of Typical Welded Assemblies* by H. B. Merriman.
Lecture 6—5th Jan.—*British Standards for Welding* by R. Partridge.
Lecture 7—12th Jan.—*Design Considerations of Fatigue, Brittle Fracture and Residual Stresses* by R. P. Newman.
Lecture 8—26th Jan.—*Control of Distortion* by E. H. Lee.
Lecture 9—2nd Feb.—*Control of Weld Quality* by A. H. Goodger.

The lectures will be held at the Chartered Auctioneers' and Estate Agents' Institute, Regent House, St. Philip's Place, Colmore Row, Birmingham 3, and will commence at 6.0 p.m. Lectures will normally be of two hours' duration. Tea and biscuits are available before the lecture at a cost of 1*s* 0*d* per person.

Visiting Lecturers from France, Germany, and Belgium

In November the School organised the second of the Advanced Courses for Welding Engineers. One of the objects of the advanced courses is to give British welding engineers the opportunity of learning first hand of developments in foreign countries and to provide an opportunity of discussing problems of mutual interest with leading experts from abroad. This year, five leading foreign authorities visited the School:

M. H. P. Granjon, Ing. ESSA, Lès.S.—Engineer and Director of Studies at the Ecole Supérieure de Soudure Autogene, Institut de Soudure, Paris;
Dr. H. Krautkramer, Dr.rer.nat.—Gesellschaft fur Electrophysik, Cologne;
Professor W. Soete, Ir.—Director, Laboratorium voor Weerstand Van Materialen, University of Gent, Belgium;
Dr. R. Sohngen, Ing.—Farbenfabriken Bayer A.G. Leverkusen, W. Germany.

BRANCH NEWS

Birmingham — Chairman's Address

At a well attended first night meeting of Birmingham Branch members heard their Chairman, Mr. N. Jones, deliver his inaugural address.

Mr. Jones entitled his lecture "*How the other half live*", and opened by illustrating how a large electrical equipment manufacturer set up to mass produce car equipment, and stressed the complex organisation which backed the operation.

Mr. Jones then switched to the 'Other half' and showed how in contrast the smaller industries in the Birmingham area used traditional skills and techniques to produce specialised products. Mr. Jones illustrated examples of work in little known fields where welds had been made in conditions which, in the larger industrial concerns, would be considered 'difficult' if not impossible. As an example of this, samples were shown in which brass had been resistance welded to chromium plated mild steel; also wire welds which displayed no upset although the welds were perfectly satisfactory.

One of the most interesting facts of Mr. Jones's address dealt with the metal joining carried out in the jewellery trade. He pointed out that with goods of assay quality, the brazing alloys (called solders by the trade) had to be very close to the composition of the parent metal; this of course brought the melting temperature of the joining alloy perilously close to that of the parent metal. The brazing techniques and equipment used by the silversmith had not changed a great deal over the centuries but Mr. Jones had found that, to duplicate the silversmith's brazing in a furnace, a temperature control to within $\pm 10^{\circ}$C. was necessary.

Mr. Jones concluded by saying that, in his opinion, there was scope for the use of more advanced techniques in most of the craft industries if only the information could be transmitted to them. He suggested that the Institute was the most likely body to perform this function.

A spirited discussion followed in which speakers defended the traditional industries and considered it would be to the industries' loss to lose the craftsmen's skill. The vote of thanks seconded the meeting's appreciation for an unusual and interesting address.

J.R.M.

Manchester — Nuclear Power

The Winter Session opened on 4th October, 1961, when a lecture entitled "*Welding and the nuclear power programme*" was presented by Dr. A. B. McIntosh, of the United Kingdom Atomic Energy Authority Industrial Group. This was also the occasion of the first Branch meeting to be held in the extremely well appointed lecture theatre in the Literary and Philosophical Society's new building at 26 George Street, Manchester 3.

Dr. McIntosh commenced by referring to the special steels involved in the manufacture of nuclear power pressure vessels, pipework etc., and to the considerable amount of research work done by the steel manufacturers, in conjunction with the U.K.A.E.A., Industrial Group, to enable the steels to be produced. With the aid of lantern slides he described some of the numerous and complicated experiments which had been done by the Authority, so that correct welding techniques and applications could be applied, so very often in confined spaces and under difficult site conditions, by the Contractors involved. We were also told of the extremely high standard of welding fabrication required in this industry in order to combat corrosion problems, and also the fact that with so much of the work, once it was put into service in a nuclear power station, it could not be touched or gained access to, due to radiation from the nuclear power source. Finally, a most interesting sound and colour film was shown which described and showed work in progress at various nuclear power station sites, including welding and erection of reactors, heat exchangers and other large units.

The evening concluded with a lively question period in which members and visitors took part, and a vote of thanks to Dr. McIntosh was proposed by Mr.

C. D. Askew, a member of the Branch Committee.

A.C.M.

North London

Arc Forces

The North London Branch opened its new season of lectures on Wednesday, 27th September, at Princes Gate, when the first lecturer was Mr. J. C. Amson, Senior Research Officer in charge of the Arc Physics Group, British Welding Research Association.

His subject was "*The arc and its forces*", and this proved to be a most instructive lecture. In conjunction with his excellent way of putting over the technicalities in an easy-to-follow language, he also illustrated in graphic detail the many facets of this most fascinating subject by the use of slides for diagrams and graphs, and also by colour films. He discussed in great detail the many equations, forces and analysis, which had great bearing on the subject. The forces he named, Fluid Conductor and Larenz Force, were easily explained by him, and he took great effort to break everything down, rendering his subject into a language that all members and visitors could readily digest. Using slides, he portrayed graphs, where calculations tied up with practical experiments, and the first film, which followed, gave some most remarkable examples of the action of the arc, where speed, diameter, and amperages were varied. One remarkable part of this film showed the weld metal 'spiralling' or 'trunking' at a speed of 1,000 revolutions per second.

The second film, also by B.W.R.A., showed the running conditions, using aluminium core wire, and copper core wire, with shrouding by argon, nitrogen and carbon dioxide. Mr. Amson went into great detail to explain the phenomena applicable to each material, shrouding, and amperages, and the notable features which were so graphically illustrated, in full colour, taken at a speed of 5,000 frames per minute.

Many interesting questions were put to Mr. Amson, who dealt with them most ably, to the continued interest of those present. One of the two lady visitors, Dr. Alina Borucka, brought forward very interesting questions, displaying an obvious great knowledge of the speaker's subject.

A vote of thanks was proposed by the Assistant Secretary of the Branch, who said that it was a privilege to be asked to perform this duty, as one of the many present who, having used the arc on a practical basis for many years, had been most impressed by the great wealth of information obtained from the lecture, and from the excellent films and graphs used to show the phenomena known as the arc.

R.B.W.

South London

Medway Section Welding Economics

The 1961–62 session of the Medway Section was opened on 27th September, 1961, with a meeting held at the Sun Hotel, Chatham.

The Chairman, Mr. D. N. A. Hancock, opened the meeting by paying tribute to the work carried out by the previous Chairman, Mr. L. A. Lidstone, which had succeeded in maintaining the high level of activity in the Section.

Mr. J. K. Johannesen of the British Oxygen Company Ltd. gave his paper "*Economics of arc welding*" illustrated with a large number of slides. The effect on cost of positional welding was discussed in detail and also methods of design to reduce costs. A lively discussion period followed, which effectively demonstrated the interest of the members and visitors in this subject.

The vote of thanks was given by Mr. R. L. Gaughan.

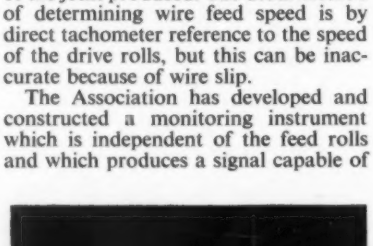
D.W.D.

BRITISH WELDING RESEARCH ASSOCIATION

Wire speed measurement

In consumable electrode welding, where the electrode wire is fed from a spool into the weld zone, the rate of feed has a critical influence upon the quality of the joint produced. The usual method of determining wire feed speed is by direct tachometer reference to the speed of the drive rolls, but this can be inaccurate because of wire slip.

The Association has developed and constructed a monitoring instrument which is independent of the feed rolls and which produces a signal capable of



reproduction either on an oscilloscope or as a direct 'inches per minute' meter reading. The wire itself drives a milled spindle to the end of which is attached a disc having regularly spaced slots around its periphery. As the disc rotates a light beam from a small lamp is interrupted, so varying the electrical resistance of a photoelectric cell at a rate of 72 cycles per revolution of the driving spindle.

The change in electrical resistance, applied to a transistorised amplifying circuit, produces a square wave output signal which is fed into an electronic frequency meter coupled to a direct reading 'inches per minute' scale.

For maximum accuracy the instrument is calibrated for 0–30, 0–300, and 0–600 in./min, the entire scale being used in each range, which is selected by means of a switch.

Since the value of the light energising the photo cell must remain constant, a position is provided on the selection switch for measuring the output of the 6 volt battery supplying the lamp. A minimum value is indicated on the meter scale below which the accuracy of the instrument falls off, and this serves as a warning that the batteries should be replaced.

The monitoring head itself measures 3 in. dia. by 1 in. deep and is small enough to be incorporated into the drive roll housing of many commercially available wire feed units. It will handle wire up to $\frac{1}{8}$ in. dia.

An additional use for the monitoring instrument is in measuring traversing or rotating table speeds in mechanised welding operations.

NEWS FROM INDUSTRY

New Extensions at Murex

Extensions costing in the region of £350,000 have recently been completed at the works of Murex Welding Processes Ltd., Waltham Cross. The new buildings consist of a 500 ft long single-storey production shop with an uninterrupted floor area of 62,000 sq.ft for the manufacture of electric arc welding plant, and a two-storey office block of 7,200 sq.ft to accommodate the plant sales department, drawing office, and works engineer's department.

The extensions represent a further stage in the planned development of the Murex works, which at the time of its erection in 1938 was considered to be the largest all-welded single-storey factory in Europe. The new buildings are designed to provide the additional accommodation required to meet the consistently increasing demand for Murex metal-arc welding electrodes and equipment both at home and abroad.

The all-welded steel frame and roof construction of the new plant shop follow the same design as that of the original factory building which created widespread interest by demonstrating the large uninterrupted floor areas that could be obtained by means of welded construction.

Murex "Vodex" and "Fastex 5" metal-arc welding electrodes and Murex welding equipments were exclusively used for all the welded construction of both buildings.

(Left to right): *Mr. D. Semper, Mr. L. J. Hancock, Professor E. C. Rollason, Mr. E. Seymour-Semper, and Councillor Mrs. M. A. M. Cooke inspecting the early Hancock cutting machine.*

Presentation of Oxygen Cutting Machine to Birmingham Museum

On Friday, September 29th, Professor E. C. Rollason, Professor of Industrial Metallurgy at the University of Birmingham, presented to the Birmingham Museum of Science & Industry the oldest working oxygen cutting machine manufactured by Hancock & Co. (Engineers) Ltd., of Croydon, Surrey. This machine, made in 1924, was in constant use at the factory of Messrs. Davies Brothers & Co. Ltd., of Wolverhampton, who won a competition organised by the manufacturers to find the oldest machine still being used. The runners-up produced Hancock oxygen cutting machines manufactured in 1925, and the first ten machines entered were all manufactured before 1930.

Professor Rollason paid tribute to the manufacturers and to the Museum authorities, and he signalled the handover by cutting his initials out of a piece of steel on the machine. The reply on behalf of the Museum was made by Councillor Mrs. M. A. M. Cooke, Chairman of the Art Gallery and Museum Committee, who thanked the manufacturers and Professor Rollason for their contribution to a memorable event in the Museum's history.

International Engineering Exhibition

The largest International Exhibition ever to be held in Britain will occupy both Olympia and Earl's Court from 23rd April to 2nd May, 1963.

To meet changing European trading conditions the long-established Engineering, Marine, Welding and Nuclear Energy Exhibition is to be transformed into a huge international exhibition using the million square feet of the two exhibition buildings combined.

The exhibition will be called The London International Engineering Exhibition and has been timed partly to overlap the Hanover Fair in West Germany. Buyers from all over the world will be able to see both these great events in one short visit to Europe and will therefore be attracted to come to both exhibitions in larger numbers than before.

The joint organisers are F. W. Bridges and Sons Ltd., who have run the long-established Engineering, Marine, Welding and Nuclear Energy Exhibition since its inception in 1906, and Industrial and Trade Fairs Ltd., who organised the successful British Trade Fair in Moscow earlier this year.

The stand area of the exhibition will cater for every type of engineering product from the largest items of capital equipment to the smallest power tools and components. Olympia will, in general, take the heavier exhibits including a welding section—an exhibition in itself—while at Earl's Court electrical engineering and a range of lighter products will be on display.

STUB ENDS

▶A new International Journal, "*Materials Research*" will be published quarterly by Heywood & Company, starting in 1962. The underlying theme of the new journal will be that of the development of techniques for controlling the quality of engineering materials from a knowledge of their structure and from an understanding of how structural factors influence their properties.

▶An interesting survey of "*Welding advances adapted to maintenance*" by Mr. E. Flintham opened one of the afternoon discussion groups at the First National Maintenance Conference held in November.

DIARY

4th-8th Dec.—School of Welding Technology—Course D.3/3 "*Design for welding in general engineering*".

5th Dec.—South Western—A welding forum (Congregational Hall, Avonmouth, 6.15 p.m.)

6th Dec. — Manchester — "*Improved steels and their weldability*" by F. J. Wilkinson (Manchester Literary and Philosophical Society, George St., Manchester, 7.15 p.m.)

7th Dec.—N.E. Tyneside—"*Details of welded hull design*" by H. J. Adams
Wolverhampton — "*Electro-slag and electro-gas welding*" by W. K. B. Marshall (Wulfrunians Club, 7.30 p.m.)

11th Dec. — Sheffield — Joint meeting with Sheffield Branch of the Institution of Production Engineers (Grand Hotel, Sheffield, 7.15 p.m.)

12th Dec.—Leeds—"*Welding in structural engineering*" by J. S. Allen (Victoria Hotel, Bridge St., Bradford, 7.30 p.m.)
Liverpool—"*Welding of the yellow metals*" by M. K. Williams (Liverpool College of Technology, Byrom St., Liverpool, 7.15 p.m.)

13th Dec.—North London—"*Modern welding techniques and inspection of aluminium welds*" by D. G. W. Claydon and H. C. Constantine (Joint meeting with South London Branch) (54 Princes Gate, London S.W.7, 7.0 p.m.)

14th Dec. — Leeds — Annual Dinner (Hotel Metropole)
Southern Counties—"*Hampshire Rural Industries Bureau: Welding machines and equipment*" (Southampton)

15th Dec.—North London (Slough)—"*The all-welded Maidenhead Bridge*" by J. S. Allen (Lecture Room, Slough Community Centre, Farnham Road, 7.30 p.m.)

20th Dec.—West of Scotland—"*Welding of piping installations for power stations*" by J. Hammill

3rd Jan. — Manchester — "*Fundamental metallurgical considerations and effect of gases in welding*" by W. D. Biggs (Manchester Literary and Philosophical Society, George St., Manchester, 7.15 p.m.)

4th Jan.—Institute of Welding—Annual Lecture to Young People by J. Strong (54 Princes Gate, London S.W.7.)
N.E. Tyneside—"*The archaeology of metal fabrication*" by Dr. D. F. Tylecote.

Current WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

Arc, 1961, No. 1, Spring

Argonarc and its applications (2–6)
Flux materials (14–17)

Arc, 1961, No. 2, Summer

Argonarc on Clydebank (5)
Flux materials (6–9)
Welding technique. Part 1 (10–13)
Through the electron microscope (21–24)

Automatic Welding (U.S.S.R. Trans. B.W.R.A.), 1960, No. 8, August

Rational planning of technological processes for the fabrication of welded structures, M. I. Kalinin (5–8)
Joints in types St.5, 45, and 40Kh steels welded without subsequent heat treatment, A. E. Asnis and L. M. Gutman (9–19)
Electrodes for welding ship hull skins made of SKhL steels, N. I. Kakhovskii and others (20–25)
Chemical composition of the σ phase in austenitic 25–20 welds, Yu. B. Malevskii and others (26–28)
Similarity criteria used for determining resistance welding conditions, V. K. Lebedev and Yu. D. Yavorskii (29–36)
Single-phase and three-phase core-type transformers for multi-electrode resistance welding machines, S. M. Taz'ba (36–41)
Some technical and economic figures for welding production in mine machinery construction, K. I. Kogan (41–48)
Mechanised methods of surfacing with aluminium bronze compared, V. V. Podgaetskii and S. A. Opanasenko (48–56)
Experience of mechanised welding in the production of diesel engines for locomotives, L. D. Veretnik (57–62)
Effects of external cooling on the quality of seam welded joints, V. N. Bernadskii and G. A. Boiko (62–69)
Semi-automatic CO_2 welding in the manufacture and repair of equipment for press forging and die casting, Yu. N. Zaitsev and others (71–73)
Mechanical properties of the metal deposited when hardfacing type 45 steel by the CO_2 process, V. A. Shebanov (73–76)

Automatic Welding (U.S.S.R. Trans. B.W.R.A.), 1960, No. 9, September

Deformations in electro-slag welding, V. A. Vinokurov and A. S. Gazaryan (1–9)
Electromagnetic stirring of the slag and metal pools in the electro-slag process, D. A. Dudko and I. N. Rublevskii (10–14)
Removal of non-metallic inclusions from the metal when remelting by electro-slag process, Yu. V. Latash and others (14–21)
Microscopic heterogeneity in welds, B. A. Movchan (22–30)
Interlayers between crystals in welds, V. V. Podgaetskii and Yu. B. Malevskii (30–41)
Wear resistance of deposited metal subjected to friction at high temperatures, M. I. Razikov (35–39)
Anisotropy of the mechanical properties of welds made between thick plates with austenitic electrodes, V. S. Aristov (42–46)
A plant for welding components made of refractory and reactive metals by electron beam, S. M. Gurevich and others (47–52)
The electro-slag welding of 14 mm thick metal, I. V. Fed'ko and B. F. Lebedev (52–55)
New portable diesel generators for welding pipe lines, A. S. Fal'kevich and K. K. Khrenov (56–59)
A remote control welding current regulator, G. A. Struve (59–61)
The automatic welding of thin-walled vessels, E. F. Telezhnikov and P. A. Stasilovich (62–67)
Equipment for the submerged arc welding of longitudinal joints in pit props, M. D. Litvinchuk and others (68–72)
Spindle coupling steel slide blocks automatically surfaced with bronze, S. Ya. Shekhter (73–77)
The welding of components having one side in water, V. M. Chebanov (77–81)
Cored electrode strip, Yu. A. Yuzvenko (81–82)

Automatic Welding (U.S.S.R. Trans. B.W.R.A.), 1960, No. 10, October

The static strength of weld structures, V. V. Shevernitskii (1–8)
The effect of electro-slag remelting on the quality of the 0Kh 18N9 and 1Kh14N19V3B (EI851) stainless steels, B. I. Medovar and others (8–15)
The technical and economic figures for fusion in automatic electro-slag welding with plate electrodes, F. F. Benua and A. I. Katler (16–19)

The distribution of arc heat between the flange and web of a T-joint when welding by submerged arc, A. A. Kazimirov and V. I. Tereshchenko (20–25)

Metal transfer in CO_2 welding, L. M. Ronskii (25–32)

The inert gas-shielded welding of commercial grade molybdenum, N. A. Ol'shanskii (32–37)

A programme master voltage setter for automatic welding condition regulators, V. N. Nikulin and V. I. Skurikhin (38–41)

Automatic welding of the cylindrical part of a hot blast stove body, B. F. Lebedev and G. A. Yakimishin (47–52)

Experience of the adoption of automatic submerged arc welding, P. V. Mumrikov (53–56)

The electro-slag surfacing of ferrous with non-ferrous metals, V. I. Svetlopolyanskii and others (57–59)

The corrosion resistance in hydrochloric acid saturated with chlorine of welded titanium tubes, A. T. Konyushenko and R. V. Golovkin (60–65)

A device for measuring the thermal expansion of metal during roller-spot welding, V. V. Gorskii and L. T. Babkin (66–75)

The present state of welding science and techniques in the Chinese People's Republic, Yu. N. Gotal'skii (75–84)

Fresh data on the electrical conductivities of fluxes, V. V. Podgaetskii and L. A. Gerasimenko (84–87)

Canadian Welder, 1961, vol. 52, May

Ultrasonic weld inspection, J. v.d. Andel (10–12)

Automatic large-diameter pipeline welding (28–30)

Canadian Welder, 1961, vol. 52, June

Welding in the steel mill, T. W. McAuley (8–12)

Resistance welding clad and dissimilar metals, R. D. Engquist (14–16)

ESAB Revue (France), 1961, No. 1

Use of welding in the construction of a large capacity conveyor belt, C. J. Westberg (1–10)

New applications of arc welding under powdered flux, E. Jensen (11–20)

Founding Welding Production Journal (South Africa), 1961, vol. 1, May

Heavy plate welding in the power industry, H. Harris (3–10)

Grinding wheels in the foundry industry, S. M. Gray (13–20)

Journal of the Japan Welding Society (Japan), 1961, vol. 30, May

Unisothermal austenite decay in electric arc welding, Andrej Havalda (18–26)

Temperature distribution in welding bead, K. Nakane and T. Fujimoto (27–38)

The weldability of casting aluminum alloy (1), A. Uchida (39–46)

Oxygen in mild steel weld metal (report 2), K. Kato (47–52)

Welding of pure zirconium in controlled atmosphere, H. Suzuki and others (53–71)

Journal of the Japan Welding Society (Japan), 1961, vol. 30, June

Relation between welding defects and mechanical strength for welded joints, M. Watanabe and K. Kamachi (4–14)

Effect of undercut depth on fatigue strength of welds, Y. Tada and others (15–21)

Effects of alloying elements on notch toughness of basic weld metals (report 7), H. Sakaki (22–25)

On the ductility and hardness in the weld heat-affected zone of high strength steels, H. Suzuki and others (26–34)

Some metallurgical investigations on the causes of fisheye formation, S. Ando and S. Mori (35–45)

Spot welding of zirconium and zircaloy – 2 alloy sheets, H. Suzuki and others (46–56)

Study on high-manganese 347 electrodes, Y. Ito (57–62)

La Saldatura Autogena (Italy), 1961, No. 3, May–June

Welding in inert gas: the CO_2 process (50–65)

Przeglad Spawalnictwa (Poland), 1961, vol. 13, May

Abrasion resistance of hardfaced metals, P. Solski (117–122)

Welding of cooling elements of open-hearth furnaces, H. Korporowiez and M. Kostas (122–126)

Modern welding methods applied to repairs in steel works, S. Dobke (127–130)

Welding of gas and oil pipelines (part I), E. A. Juffy (130–140)

Repair by welding of high manganese (11G12) steel castings, B. Kolakowski (141–144)

Przeglad Spawalnictwa (Poland), 1961, vol. 13, June

Forces in the electric welding arc (part I), S. Klosowski (145–151)

Abrasion resistance of hardfaced metals (part II), P. Solski (152–156)

Ultrasonic brazing of aluminium and of its alloys, J. Gorczynski (157–162)

Tests on abrasion resistance of hardfaced surfaces of blast furnace closings, S. Krajewski (162–168)

Welding of gas and oil pipelines (part II), E. A. Juffy (169–171)

Schweisstechnik (East Germany), 1961, No. 7, July

Problems of resistance and endurance of welded aluminium joints, Alexis Neumann (291–296)

Application of group technology according to Mitrofanov to resistance welding, Kurt Seeman (297–298)

WIG copper welding, W. Raidt and M. Gerlach (299–304)

Welding of reinforcing bars using the CO_2 protective gas process (semi-shell welding), K. Friedrich (304–307)

Status of development and applicability of arc metallization (part I), E. Kretzschmar (308–312)

Immerged arc welding of thick section solid web connections, A. Fichte (312–316)

Sintered hard material hard facing alloy, R. Kohlermann and W. Ebert (317–319)

Use of CO_2 protective gas welding in brown-coal mines, Erich Jagel and Reinhard Paulig (320–323)

Damages and repair welding in vehicle construction, Hartmut Linke (324–328)

Schweisstechnik (Berlin), 1961, vol. 11, June

Mechanics of brittle fracture: a survey of hitherto published literature (2nd part), A. A. Wells (266–269)

Training and proving of young welding engineers, progress in training, W. Raidt (270–273)

Reconstruction by welding in a railway repair shop, L. Hopke (273–277)

Planning for reorganisation with particular reference to the welding technique, D. Klubescheidt (278)

Schweisstechnik Soudure (Switzerland), 1961, vol. 51, July

Welding technique in the construction of commercial vehicles, M. W. Kaufmann (237–245)

High quality welds for reactor construction, E. B. LaVelle (245–252)

Schweisstechnik Soudure (Switzerland), 1961, vol. 51, August

Tungsten electrodes for TIG arc welding, Gustav Purt (274–283)

Permissible constraints of welded machine parts, Richard Hanchen (267–274)

Schweissen und Schneiden (Germany), 1961, vol. 13, July

Load tests with brazed joints for steel pipes and sheets, H. Koch and K. F. Zimmermann (263–270)

New foreign developments in the field of brittle fracture, K. Ruhl (271–278)

Souder: Revue Pratique du Soudage (Paris), 1961, No. 30, June

Modern brazing techniques. Part 4 (7–11)

Bronze welding. Part 3 (12–14, 39–40)

Mechanical properties of welds, their determination and importance (33–35)

The welding and brazing of some cobalt-containing alloys. Part 2 (36–38)

Soudage et Techniques Connexes (Paris), 1961, vol. 15, May–June

Comments on the tentative specifications relative to arc welding electrodes, A. Gaubert (168–174)

Recent developments of resistance welding equipment in production fabrication, J. Negre (175–183)

Monographs on fatigue failures, International Institute of Welding: Commission XIII (185–194)

Memorandum on low voltage safety devices, IIW Commission II (195–198)

Study of the behaviour of brazing filler metals using a specimen with variable gap, B. Blanchet (199–210)

Technique for spot welding low carbon steel from 0·022 in to ⅛ in., IIW Commission III (211–218)

Some problems concerning the fusion welding of wrought aluminium and aluminium alloys, H. Gerbeaux (219–237)

Welding Engineer (U.S.A.), 1961, vol. 46, June

It's position that counts (37–40)

Automatic arc welding (41–43)

Will push-button welding replace pipeline welders, F. T. Tancula (46–47)

Space age requirements spur resistance welding innovation (54–55)

Welding Engineer (U.S.A.), 1961, vol. 46, mid-June

Design for welding, T. B. Jefferson (5–16)

Welding Engineer (U.S.A.), 1961, vol. 46, July

Giant radio-telescope will tune-in outer space (35–37)

Aluminum alloy bids for larger share of cryogenic market (38–39)

How to deposit hardfacing alloys (40–41)

Ship repair firm yields heavily on welding, F. T. Tancula (44–45)

Welding Engineer (U.S.A.), 1961, vol. 46, August

The shielding gases . . . their function in the arc welding (35–38)

Will Mig and Tig meet your needs? W. G. Schumacher (40–41)

Miles of CO_2-shielded welds fabricate railroad hopper cars (42–43)

Revolving Tig unit cuts costs, but maintains quality, W. Twity and W. Purcell (44–45)

Weldment-casting design improves riveters (46)

Vapor-cooled transformer speeds pipe, tube welding (55)

Welding Fabrication and Design (Australia), 1961, vol. 4, May

Developments and techniques in resistance welding, R. W. Ayers (5–9)

Selecting a power source for arc welding, J. E. Hinkel (10–11)

Welding Journal (U.S.A.), 1961, vol. 40, July

Horizontal joints in oil storage tanks, Paul W. Turner (707–713)

Consumable electrode spot welding, J. A. Howery and G. F. Mack (714–722)

Series spot welding of missile fins, D. W. Herold (723–725)

Inconel deposited weld metal for nuclear parts, R. W. Minga and W. H. Richardson (726–735)

Phenomenological considerations in ultrasonic welding, J. B. Jones, N. Maropis, J. G. Thomas, and D. Bancroft (289*s*–305*s*)

Exhaustion of ductility by hot straining, C. Mylonas and K. C. Rockey (306*s*–310*s*)

Transition temperature for test bars, Claes Pfeiffer (311*s*–314*s*)

Effect of irregular notch on subsize impact data, A. L. Lowe, Jr. (315*s*–316*s*)

Dimensional heat flow in weldments, S. S. White (317*s*–319*s*)

Weldability of a modified hot-work die steel, W. A. Sipes and E. J. Fogarty (320*s*–323*s*)

Welding PH15-7 Mo stainless steel, H. Smallen (324*s*–329*s*)

Influence of platinum metals on wettability of silver, J. B. Adamec and R. N. Rhoda (330*s*–336*s*)

Welding Journal (U.S.A.), 1961, vol. 40, August

Process for welding girth joints in steel pipelines, J. W. Nelson and others (813–820)

Importance of purity in brazing filler metals, Forbes M. Miller (821–827)

Tungsten-arc spot welding of stainless steels, J. Campbell and D. R. Miller (828–838)

Design of kraft digesters by welded overlay, Wayne L. Wilcox and Hallock C. Campbell (839–844)

Flux and filler-wire developments for HY-80 steel, W. J. Lewis and others (337*s*–345*s*)

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Shipyard modernization, D. M. Potter (247–252)

Low alloy steel welding, E. Freeth (252–255)

Fabricated design of a large guided weapon launcher, W. H. Matthews (256–258)

Explosive welding (259–261)

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Welding and Metal Fabrication, 1961, vol. 29, July

Drop tank production (274–282)

Low alloy steel welding. Part 2, E. Freeth (283–290)

Design and strength of brazed joints, M. H. Sloboda (291–296)

Chemical plant fabrication in Japan (297–300)

Orbital welding of stainless steel tube, L. Keble Hill (301–307)

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Ancillary welding equipment, A. D. Gitlevich (18–26)

Flow lines for the production of 60 m³ capacity welded rail tank cars, D. P. Antonets and others (27–34)

Mechanised flow lines for the production of welded beds of broaching machines, A. M. Avrutin and others (35–40)

Mechanisation of assembling and welding operations at Rostel'mash (Rostov-On-Don Agricultural Machinery Plant), G. P. Solodenko and others (40–46)

Mechanisation of welding at the Ural chemical machinery works, E. N. Starichenko (47–50)

A continuous automatic line for welding the sides of open-top waggons, P. I. Mazka (50–52)

Mechanised production of spirally welded tubes, S. N. Mel'bard and V. B. Krekhnov (52–54)

A production line for assembling and welding automatic dump truck bodies, M. A. Makhnin (55–57)

Automatic welding of a frame unit for the S-100 tractor, I. F. Kobzev and N. A. Karpova (57–60)

Equipment for the automatic welding of air cylinders, V. D. Kolesnikov and P. S. Stekhin (61–65)

Apparatus for measuring and regulating the welding current during resistance welding, P. L. Chuloshnikov (65–70)

The new State Standards for electrodes, V. V. Bazhenov and L. M. Yarovimskii (70–75)

The new State Standard 2246–60 for steel electrode wire, I. N. Grabov (76–79)

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The formation of cracks in compression cords of bent welded seams, O. Pucher (131–136)

Contribution to the possibilities of alloying deposit weld metal with ceramic flux, L. Pejsa (136–139)

Verification of ultrasonic indications and their documentation, S. Ludvik (139–142)

Zvaranie (Czechoslovakia), 1961, vol. 10, June

Welding of electrode and flux with electro-slag welding, M. Mosny (162–166)

Flash butt welding without preheating of thin-walled cross sections, T. Zrna (166–172)

Circulation of the flux in roll depositing, R. Rohan and F. Morys (174–177)

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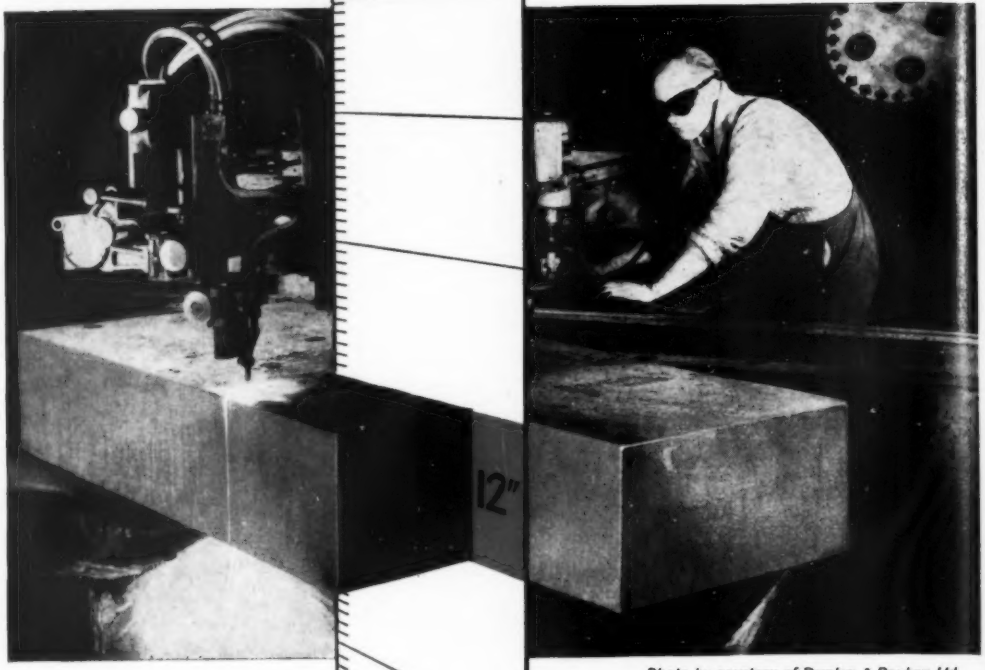

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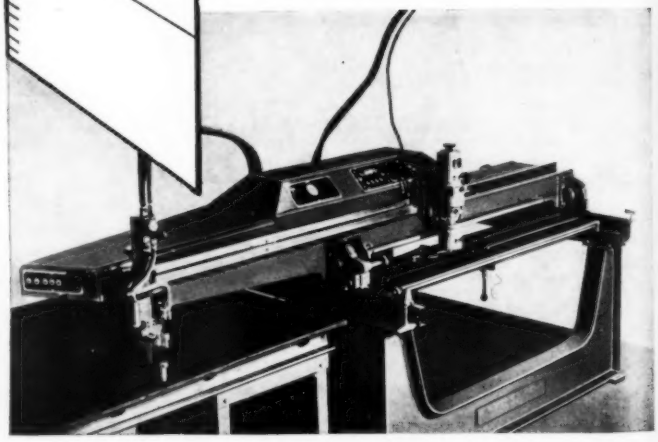

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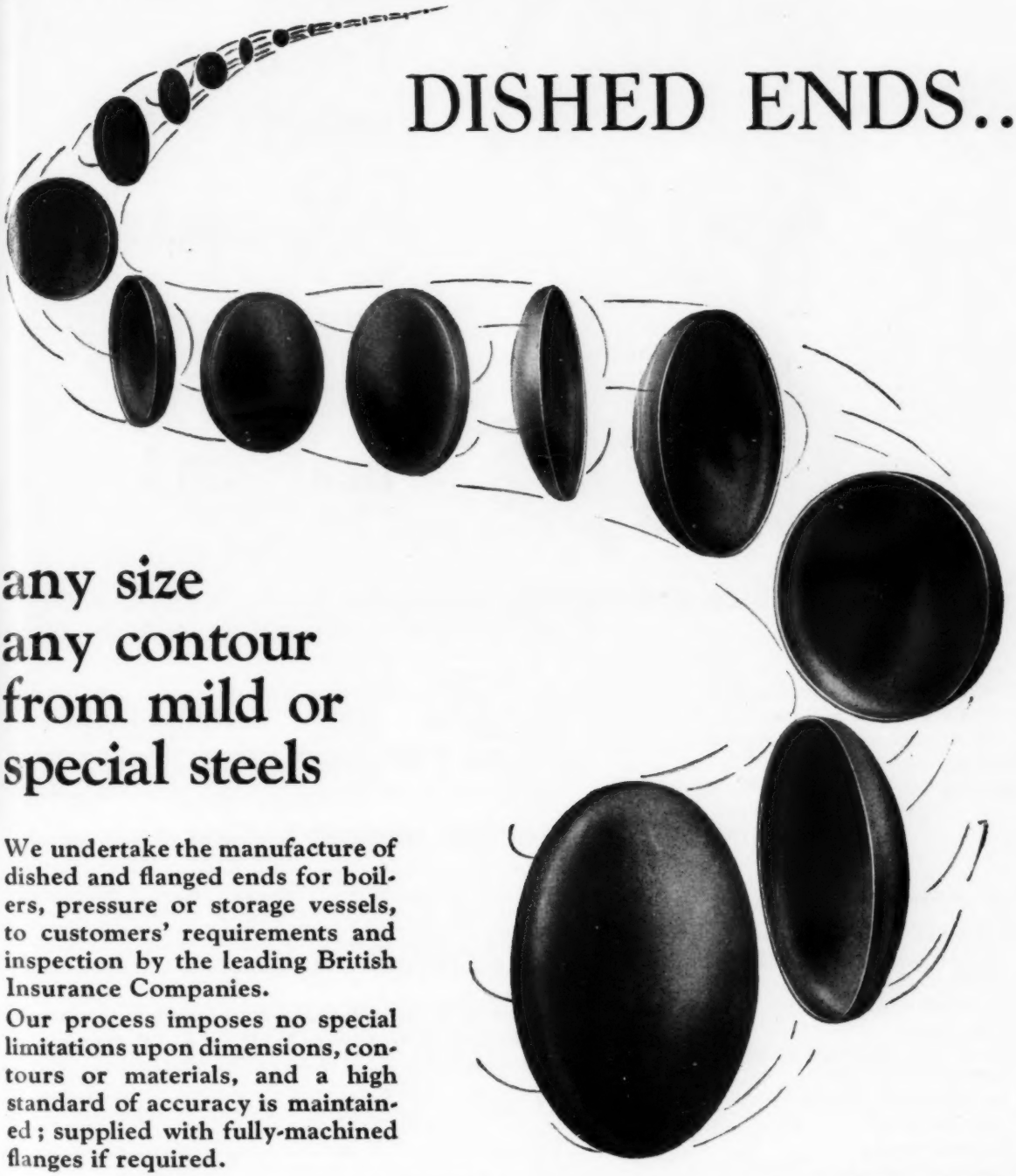

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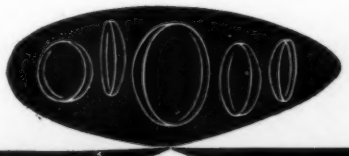

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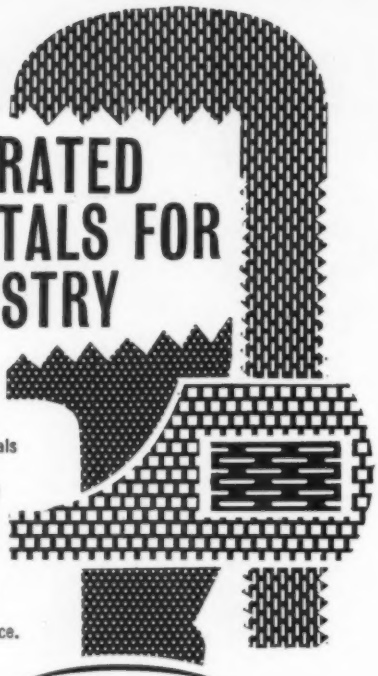

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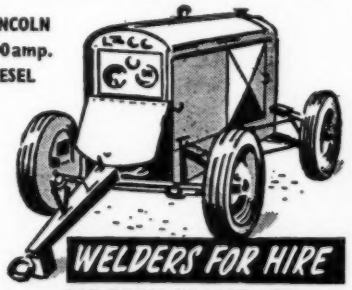

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ADVERTISERS' INDEX

Associated Electrical Industries (Manchester) Ltd.	6
Arc Manufacturing Co. Ltd.	19
Armco Ltd.	4
British Oxygen Co. Ltd.	*outside back cover* 8, 9
Butterfield, W. P. Ltd., The	24
Carver & Co.	26
Classified	25
Courtburn Supplies Ltd.	24
Distillers Co. Ltd., The	16
English Electric Co. Ltd., The	*inside front cover*
Hancock & Co. (Engineers) Ltd.	18
Hirst Electronic Ltd.	26
Ilford Ltd.	10
Interlas Ltd.	16
Imperial Chemical Industries Ltd.	2
Johnson Matthey Ltd.	7
Joseph Adamson & Co.	21
Lincoln Electric Co .Ltd.	14
Murex Welding Processes Ltd.	17
Pool, J. & F. Ltd.	24
Research & Control Instruments Ltd.	*inside back cover*
Robey & Co.	5
Rockweld Ltd.	1
Saturn Industrial Gases Ltd.	20
Smith Hugh (Glasgow) Ltd.	3
Suffolk Iron Foundry (1920) Ltd.	23
Welding Rods Ltd.	22
Welding School of Technology	23

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International WELDING

Reports on Fatigue Failures

Fatigue phenomena may affect welded as well as other constructions. Consequently, whenever a welded assembly is required to withstand cyclic stresses, those responsible for its manufacture should insure that the appropriate measures, analogous to those considered indispensable in non-welded products, are taken.

Among the great variety of types of assembly made possible by welding, may be some of equivalent static strength in service but which behave very differently under fatigue loading. Although further progress in this field may still be made, it is now known which of these types of assembly are to be recommended and which to be avoided. Commission XIII (Fatigue Testing) of the International Institute of Welding has collected critical reports on fatigue failures occurring in service in welded constructions in order that relevant information on this subject may be placed at the disposal of manufacturers. Some of these reports have been circulated for publication, following the Madrid meetings in July, 1956 and the Essen meetings in July 1957. At its Vienna meetings in July 1958 the Commission recommended the reports attached for publication.

These reports are all presented in the same form corresponding, in so far as possible, to the questions in the inquiry circulated by the Commission with a view to obtaining the information which it wished to assemble. No information is given concerning the origin or author of these reports since the information was collected on the understanding that it would be considered as having been supplied anonymously and the Commission has acted on this understanding.*

DAMAGE TO THE SHELL PLATING OF A BANANA SHIP

1. Type of construction in which failure occurred

Damage occurred to the shell plating in the forepart of a banana ship of 5,586 tons light displacement, put into service in August, 1953. This vessel, 370 ft (112·7 m) in length overall, and 51½ ft (15·8 m) in breadth, has a normal speed of 16·5 knots in service.

The structure of the forepart of the vessel consists (Fig. 1) of an upper deck, a main deck, an upper platform-deck, a lower platform-deck and a ballast tank top. The last rests on floors having the full depth of the ballast tank, while the decks and platform-decks are supported transversely by beams of various cross-sections.

The shell plating, of $\frac{7}{16}$ in.–$\frac{19}{32}$ in. (11–15 mm) nominal thickness, consists of longitudinal strakes, all the joints of which are butt welded.

At the inner bottom, this plating is supported by the floors of the ballast tank to which it is riveted.

From the ballast tank top to the upper deck, the shell plating of the vessel is braced transversely by frames riveted with $\frac{3}{4}$ in. (19 mm) rivets. These frames are made up of bulb angles, $7\frac{7}{8}$ in. × $3\frac{1}{2}$ in. × $\frac{13}{32}$ in. frames (200 × 90 × 10 mm).

Each frame is fastened at the foot to the ballast tank top by a $\frac{13}{32}$ in. (10 mm) longitudinal gusset-plate plug welded to the flange of each frame and fillet welded to the tank top.

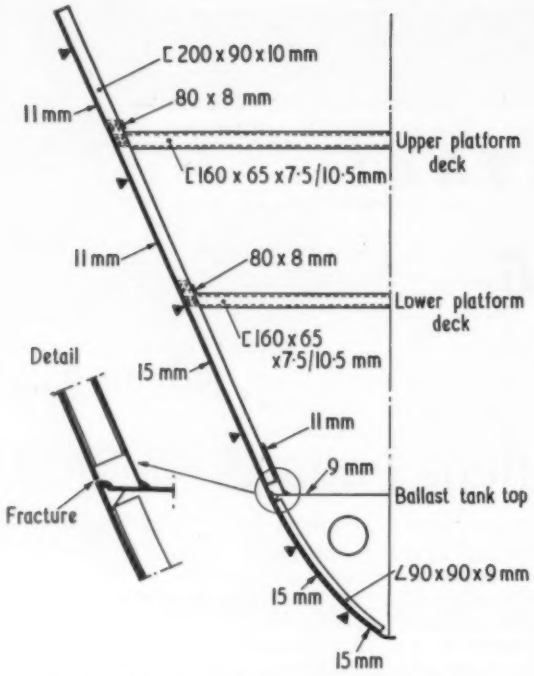
2. Stresses in normal service in the region where failure occurred

2.1. *Nature*

The shipowner was inclined to attribute this

Report IIW/IIS–14–59 of Commission XIII "Fatigue Testing" of the International Institute of Welding.

* See p. 16s.



1—*Section at frame 131—construction in No. 1 hold*

damage to fatigue caused by the action of the sea, since ships of this type roll and pitch heavily.

2.2. *Amplitude and frequency*

In this instance the amplitude and frequency of the oscillations would depend on the state of the sea. However, no steps were taken to assess their value, either in the region of the midships frame of the vessel, or in the zone where the failure occurred.

3—*Starboard side of the hull. From 125 to 138 (forward to the right). Arrows indicate cracks*

2.3. *Total duration of the application of stresses*

The only indication which is available in this respect is the total duration of service of the vessel, *i.e.* a little more than three years.

3. Information concerning the fractures and the circumstances of their appearance

3.1. *Position of the fractures*

The failure in the shell plating was discovered in November, 1956, when the vessel went into dry dock.

It consisted of a general deformation of the plating in a longitudinal line on the level of the ballast tank top accompanied by cracks running longitudinally and located facing some of the frames, principally from frame No. C125 to the collision bulkhead, No. 139 (Figs. 2 and 3).

3.2. *Extent of the fractures*

The laboratory examination of specimens taken opposite the ballast tank top and the frames, after thorough cleaning of the surfaces with a brush, revealed the various fractures enumerated in Table I, in addition to ten longitudinal fractures along the

2—*Port side of the hull. From 125 to 138 (forward to the left). Arrows indicate cracks*

Table I

Summary of cracks observed

Reference No. of strake	*Reference No. of frame*	*Length of cracks along the ballast tank top*	*Rivet holes showing cracks**	*Comments*
3 V 12	132		2nd	
Port	133		1st and 2nd	
	134		2nd	
	135	400	2nd	Figs. 4–7
	136	350	2nd	
	138	310	1st and 2nd	
3 V 12	125	140		
Starboard	130		2nd	
	131	280	2nd	
3 V 13	134	250		
Starboard	135	250	2nd	
	136	250	2nd and 3rd	
	137	280	2nd	
	138	150		

* Counting from the ballast tank top upwards

ballast tank top, fourteen other cracks were discovered, which affected the rivet holes at the base of the frames above this level.

The large longitudinal fractures were found along the weld seam fastening the upper surface of the ballast tank top to the shell plating; they were longer forward of the frame (Figs. 4 and 5), except in the instance of frame C138 where they were approximately symmetrical in relation to the frame. Along a welded joint of 108 ft (33 m), these cracks extended for a total distance of about 8½ ft (2·6 m).

The cracks observed in the vicinity of the rivet holes likewise ran approximately in the longitudinal direction, but in every instance were much shorter than those already mentioned. Each of them was found below the corresponding rivet hole. On the inside face, they had the appearance of a network made up of numerous small cracks (Fig. 5).

3.3. *Appearance of the fractures*

Once they had been opened out, and the rust had been removed, all the fractures presented a fatigue fracture surface, which started both from the inside and from the outside surfaces of the plate.

3.4. *Deductions drawn from the appearance of the fractures concerning the fracture process*

This appearance indicated that the hull plates had been subjected to bending.

So far as the large fractures are concerned, the cracks which started on the inside, *i.e.* along the weld bead of the ballast tank top, penetrated more deeply into the side than the corresponding cracks which started on the outside (Figs. 6 and 7).

It was in general the other way round with the cracks which occurred near the rivet holes.

It appears, therefore, that the bending moment operated in opposite directions in the two areas.

3.5. *Abnormal circumstances which may possibly have accompanied the fractures*

There is nothing to add here to what has been said in 2.1 above concerning the behaviour of the vessel at sea.

3.6. *Comments which may be applicable to the behaviour of other identical constructions in service*

This type of damage has not hitherto been observed on vessels of the same type.

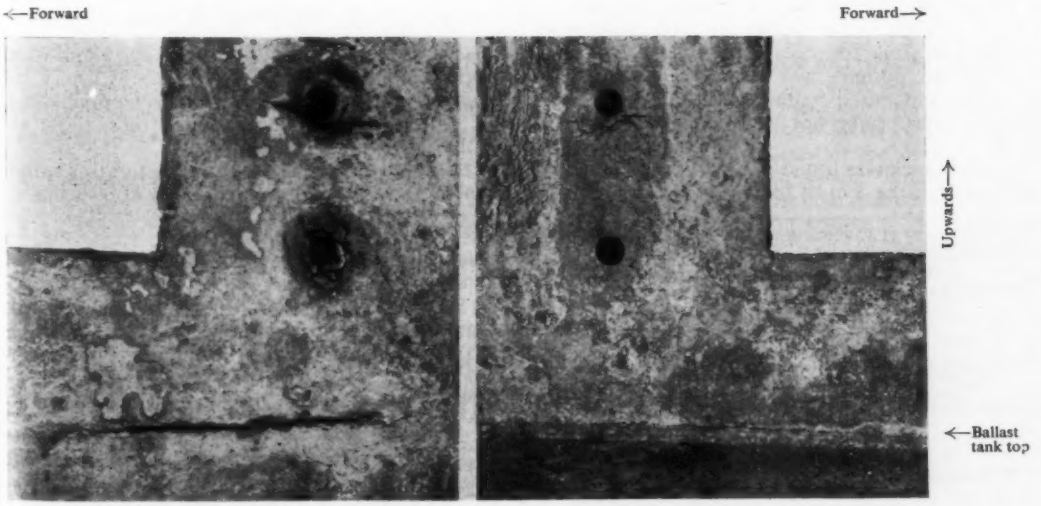
4. Type of materials in the area of fracture

The whole vessel is constructed in steel in accordance with the specification of a Classification Society with a strength of 26–31·7 ton/sq.in. (41–50 kg/sq.mm).

5. Types of welded joints affected

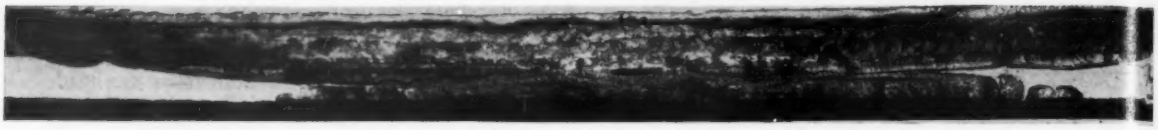
The fractures run along a fillet weld between the shell $\frac{19}{32}$ in. (15 mm), and the plate $\frac{11}{32}$ in. (9 mm), forming the ballast tank top.

Welding was carried out in accordance with the requirements laid down by the appropriate Classification Society.

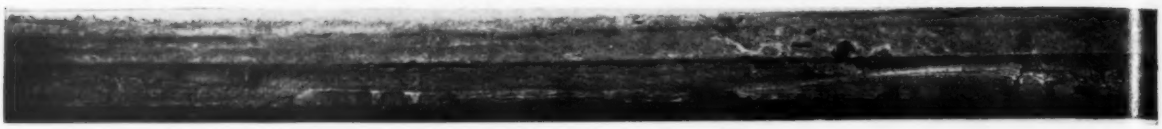


4—*External surface* 5—*Internal surface*

Figs. 4 and 5—*Shell plating at frame No. 135, port*



6—*Surface of the fracture, before derusting. External surface downwards*



7—*Surface of the fracture, after derusting. External surface downwards*

Figs. 6 and 7—*Shell plating at frame No. 135 port. Surface of the fracture along the ballast tank top*

6. Presumed causes of the accident and lessons which might be drawn from it

The S bending in two opposite directions, of a cyclic character, which caused the fractures observed, may be explained by a vertical stress directed upwards onto the bottom during pitching. The localization of the cracks would be due to the insufficient rigidity, when subjected to such a stress, of the connection afforded by a flat gusset-plate between the lower extremities of the frames and the ballast tank top and also the structure of the double bottom.

It is worthy of note that the riveted part of the structure did not suffer much less than the welded part.

WELDED STRUCTURE OF A SELF-PROPELLED HOIST

1. Type of construction in which failure occurred

The construction was a self-propelled ladder with a jib which could be raised; it was used to facilitate the replacement of lighting bulbs on the public highway.

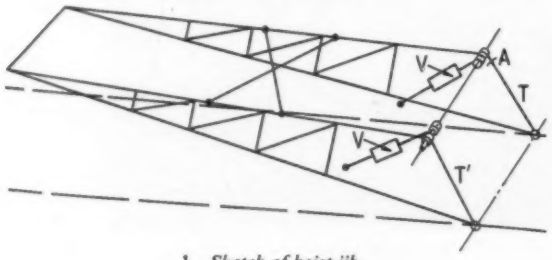
The jib or ladder was of welded tubular construction.

This ladder was formed by two tubular uprights, which were parallel and cross-braced, and together made an integral structure.

The foot of the uprights was mounted on a pivot, and the ladder was raised by the action of 2 V-jacks which engaged the uprights not far from the foot of the jib (Fig. 1).

An extensive crack was found in the section marked *A* of the tube *T* at the foot of the jib.

Report IIW/IIS–13–59 of Commission XIII "Fatigue Testing" of the International Institute of Welding.



1—*Sketch of hoist jib*

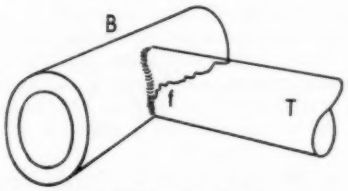
2. Stresses in normal service in the region where failure occurred

2.1—The appliance was frequently raised and lowered when lighting bulbs on the public highway were being replaced.

The position of the jacks was such that the stresses on the weldment were different from one point to another on its periphery; moreover, the eccentric position of the jacks set up a torsional moment in the tubes *T* or *T'* which served to add to the other stresses which operated upon the weldment.

2.2—It has been possible, by the use of strain gauges, to arrive at a fairly exact idea of the dynamic stresses in the tube in the neighbourhood of the weld, when the appliance was being raised and lowered.

One gauge was placed at the upper, and another at the lower part of the tube *T'*. It was found that the



2—*Detail of tee joint*

stresses alternated between 0 and 6·3 kg/sq.mm* for the upper part, and from 1 to 8 or even from 7 to 14 kg/sq.mm for the lower part; there is no doubt that higher values existed at other points than those at which the gauges were placed.

2.3—It is impossible to state the number of times that the appliance was operated. It is merely known that it was in use for three years.

3. Information concerning the fracture and the circumstances of its appearance

3.1—The tubes *T* and *T'* were assembled by welded tee-joints between both their ends and the steel bushes, as indicated in Fig. 2. The crack is in section *A* (Fig. 1).

3.2—The crack started in the tee-joint weld bead at point *f*, followed this bead for about $\frac{3}{4}$ in. (2 cm), and

* 0·63 tons/sq.in = 1 kg/mm²
4 " " = 6·3 " "
5 " " = 8 " "
4·4 " " = 7 " "
8·8 " " = 14 " "

then spread into the metal of the tube (see Figs. 2 and 3).

3.3—In the neighbourhood of point *f*, the fracture had a fine grain and showed no sign of deformation. Outside the area surrounding point *f*, a small degree of deformation and some bending strain became apparent in the tube.

3—*Fracture at tee joint*

3.4—It may be deduced from this that the fatigue crack must have been brought about by a fairly considerable number of cycles (of the order of 100,000).

4. Nature of the materials

According to mechanical tests carried out on the metal of the tube, the steel had the following properties:

Ultimate tensile strength	29 tsi (45·8 kg/mm²)
Yield point	17·8 tsi (28 kg/mm²)
Elongation on $8{\cdot}16\sqrt{S}$	24%

The result of a full bending test was good.

5. Welding conditions

The fractured welded joint was a tee-joint weld connecting a thin-walled tube at right angles to a thick-walled bush. No details are available about the welding procedure.

The thickness of the tee-joint weld bead appears to be small (less than the thickness of the thinnest wall).

6. Presumed causes of the failure

It appears that the failure was caused by:

6.1—Cyclic mechanical stresses which may have been of considerable magnitude.

6.2—Inadequate dimensions of the weld bead. In addition, the surface of the weld bead was in the rough, as-welded, state.

FATIGUE CRACKING OF THE MAIN DECK OF A WARSHIP

1. Type of construction in which failure occurred

The fracture occurred in the main deck of a warship.

This vessel had an extensive forecastle deck. To the transverse bulkhead bounding this deck aft was fastened a lighter and narrower deck house situated on the centre line of the vessel, which necessitated an expansion joint at a short distance from the forecastle.

The fracture discovered occurred in the main deck in the immediate vicinity of the weld connecting this deck to the nearest bulkhead stiffener, forward of the expansion joint, and also in the vicinity of the weld joining the deck with the bracket at the foot of this stiffener.

The fracture of the main deck was located about 45% of the length of the vessel forward, and at a distance of $6\frac{1}{2}$ ft (2 m) to port of its centre line.

The diagrams attached (Fig. 1) give precise details of the structure in the vicinity of the fracture, as well as the outline of the latter. In the region of the damaged area, the light deck-house was fitted out as a galley and a coffer-dam separated it from the main deck. An opening situated in the deck-house side and the expansion joint were located on either side of the stiffener concerned.

The stiffener was formed by an angle section with unequal flanges, $2\frac{1}{2}$ in. × 2 in. × 0·1875 in. (63·5 × 50·8 × 4·76 mm), of which the large flange, perpendicular to the deck-house side was attached to this bulkhead by a fillet weld. At the lower extremity of the stiffener, the small flange of the angle facing was a fore-and-aft stiffener under the deck, formed by an angle with unequal flanges, $4\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × 0·312 in. (114 × 63·5 × 7·8 mm). Placed against the face of the large flange of the bulkhead stiffener, a bracket $\frac{5}{32}$ in. (4 mm) thick, was secured by a weld, 5 in. (130 mm) long, to the stiffener and to the main deck.

The point of attachment of the stiffener was located appreciably aft of the plane of the nearest transverse beam.

2. Stresses in normal service in the region where failure occurred

2.1. *Nature*

Little is known of the nature of the stress to which the main deck of the vessel was subjected in the region of the fracture. It may, however, be supposed that, in addition to the tension-compression stresses caused by the working of the vessel in a swell, there was a perpendicular stress on the deck caused by the stiffener owing to the simple fact that it was fastened to the deck-house side, which was itself an integral part of the forecastle.

2.2. *Amplitude and frequency*

No indication can be given of the values of the amplitude and frequency of the stresses. They are, in fact, connected with too many variable or indeterminate factors, such as the characteristics of the swell, the speed of the vessel, the course of the vessel relative to the swell, the state of lading of the vessel, etc.

2.3. *Total duration of the application of stresses*

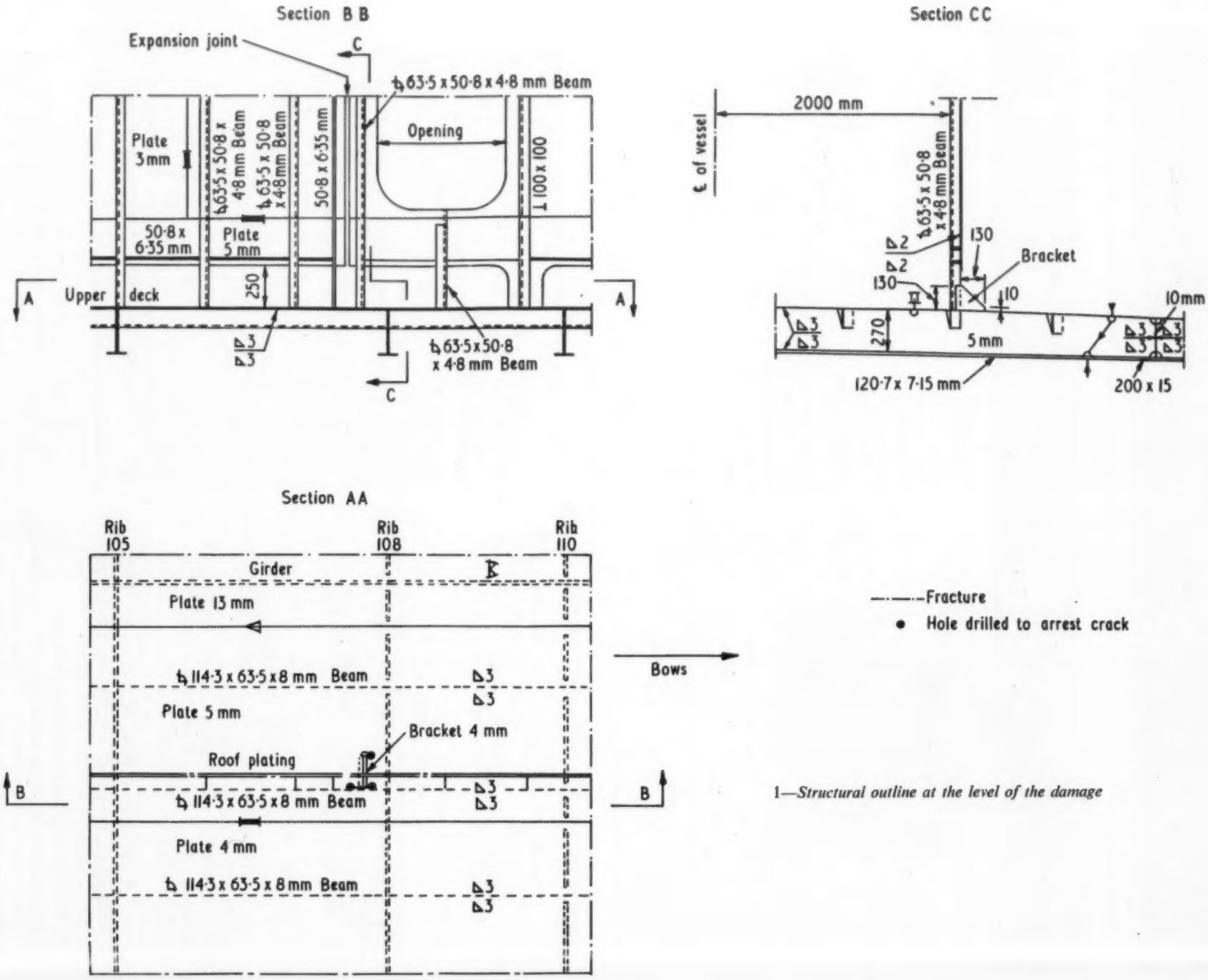
No exact indication can be given. It may, however, be mentioned that when the failure was discovered, the vessel had only done 6 months at sea, from which must be deducted the duration of periods in port.

3. Information concerning the fracture and the circumstances of its appearance

3.1. *Position of the fracture*

The fracture observed was on the port side of the vessel, and it had a cruciform outline, the short side of

Report IIW/IIS–15–59 of Commission XIII "Fatigue Testing" of the International Institute of Welding.

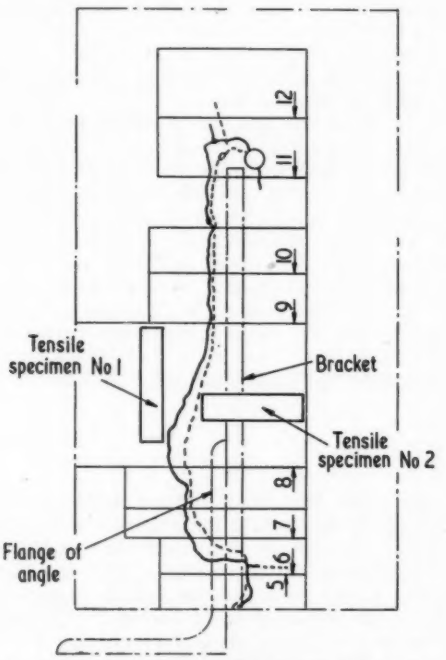


1—*Structural outline at the level of the damage*

the cross being parallel to the line of attachment of the longitudinal girder under the deck, and the long side running along the joint between the vertical stiffener and its bracket and the main deck.

3.2. *Study of the fracture*

On account of the difficulty of access to the damaged area of the deck, it was impossible to cut out the whole area in one piece and then make a detailed examination of the fracture in its entirety. Figure 2 gives the outline of that part of the crack running transversely and alongside the bracket. The solid line and the broken line show its course respectively on the upper and lower surfaces of the deck.



2—*Outline of the fracture and location of test pieces*

The photograph (Fig. 3) shows the upper side of the deck, the bottom part of the photograph being located on the side adjacent to the centre line of the vessel (*i.e.* inboard of the fracture). One of the holes that were drilled to stop the crack spreading at the time when it was discovered can be seen as well as the relative difference in levels of the two lips of the fracture; the lip connected to the forward part of the deck lies at a lower level than the other.

In the part of the deck examined, it may be observed that:

—the fracture has a tortuous outline,
—the outline runs right along the fillet weld securing the bracket and is parallel to the weld securing the stiffener,
—at certain points, particularly at the extemity of the gusset plate, this outline shows smaller branches,
—the planes of the faces of the fracture are clearly set at an angle in relation to the deck plate.

3.3. *Appearance of the surface of the fracture*

No examination was made of the surface.

3.4. *Deductions drawn from the appearance of the fracture as regards the fracture process*

From the examination of the fracture which was made before repair, it appeared that the fracture commenced along the longitudinal girder under the deck, and then continued along the bracket at the foot of the stiffener.

3.5. *Abnormal circumstances which may possibly have accompanied the fracture*

The fracture became apparent when the vessel went to sea in very rough weather; the length of the swell was $\frac{3}{4}$ to $1\frac{1}{2}$ times the length of the vessel, and its height was 26–33 ft (8–10 m). The vessel was following a course lying at an angle of about 5° to the line of the swell, and was taking it on the port quarter. The temperature of the sea-water was 5°C., and that of the air 10°C. It should be remarked that the damaged part of the deck cannot be considered to have been subject to an abnormal temperature at the time when the fracture occurred, since it lay above the engine room.

3.6. *Comments which may be applicable to the behaviour of other identical constructions in service*

Other identical vessels were examined, but they did

3—*Appearance of fracture on the upper side of the deck*

not reveal any failures of the same nature either at similar positions or at any other point.

4. Type of material in the area of fracture

Steel of 33 ton/in² (52 kg/mm²) tensile strength.

Chemical Composition

	As specified Less than or equal to, %	*As analysed* %
C	0·20	0·14
Mn	1·40	1·50
Cu	0·50	?
Si	0·50	0·41
P	0·04	0·016
S	0·04	0·033
S+P	0·07	0·049
N_2	0·008	?

Mechanical Properties

	As specified	*Measured on Specimen No.* 1	2	3
Yield Point:				
ton/in²	greater than 22·8	29	26·8	25·9
kg/mm²	,, ,, 36	46	42·3	40·9
U.t.s.:				
ton/in²	greater than 33/39	38·9	40·3	40·3
kg/mm²	,, ,, 52/62	61·3	63·6	63·6
Elongation, %	greater than 20	22	25	31·2
Reduction in Area, %		58	69	57·8

1 and 2 were measured on Hounsfield test-pieces and were taken respectively parallel and at right angles to the crack.

3—rectangular section test-piece, $\frac{5}{32}$ in. × $\frac{1}{16}$ in. (3·91 × 8 mm), taken from the deck plate where a second crack occurred during repairs to the deck. This plate was adjacent to the one in which the fatigue fracture occurred.

Electrode—The electrode used had a basic coating, and was of a type depositing metal with 31 tons/in² (49 kg/mm²) minimum tensile strength. The appearance of the beads was satisfactory.

5. Type of welded joint affected

The fracture observed affected the fillet weld joining a deck plate, 0·23 in. (6 mm) thick, with an angle section, $2\frac{1}{2}$ in. × 2 in. × 0·1875 in. (63·5 × 50·8 × 4·76 mm), and its gusset-plate, $\frac{5}{32}$ in. (3 mm) thick.

6. Presumed causes of the accident and lessons which might be drawn from it

The cause of the fracture seems to have been the effect of pounding of the vertical stiffener and its gusset-plate on the main deck.

In support of this opinion, it should be remarked that after this fracture was discovered, three holes, $\frac{1}{4}$ in. (6 mm) in diameter, were drilled at its extremities to prevent it spreading, and the upright was cut away with an oxygen torch to make it independent of the deck; no further extension of the fracture was observed, although the vessel remained at sea for a further two days in the same rough weather.

The repair of this part of the structure was effected by establishing an elastic connection between the galley bulkheads and the main deck. Since then, no further trouble has been observed.

FRACTURE OF THE BULKHEAD STRINGERS OF A TANKER

1. Type of construction in which failure occurred

The damage occurred in the transverse and longitudinal bulkhead stringers of a tanker, 520 ft (158·5 m) long between perpendiculars, $67\frac{1}{2}$ ft (20·6 m) beam, and of 6,502 tons net tonnage.

The construction of this vessel (Fig. 1) in the area of the tanks, that is to say, throughout the greater part of its length (Fig. 2), consisted of a single deck supported by transverse web frames and longitudinal bulb plates.

The side shell plating was stiffened by vertical channel frames and three horizontal stringer girders. The bottom shell plating was supported by T-bar longitudinals, transverse girders and a continuous longitudinal keel girder.

The transverse bulkheads were stiffened vertically by bulb plates, and transversely by three horizontal stringers placed on the level of the side shell stringers.

The longitudinal bulkheads were stiffened vertically by bulb plates and by channels, and horizontally by stringers corresponding to the stringers of the sides of the vessel, which were all located outboard of the bulkhead, that is, in the side tanks. In addition, horizontal girders of $\frac{240}{11} \times \frac{240}{18}$ mm I-section, running across the side tanks, formed ties between the sides of the vessel and the longitudinal bulkheads.

The joint between the stringers at the corners of the central tanks was formed by a fillet weld. In addition, there was a horizontal bracket with a flanged edge, welded on the one hand to the bulkhead plate and on the other to the stringer, as is shown in Fig. 3.

The same layout was adopted in the transverse tanks except that the bracket was not attached to the longitudinal bulkhead or the side shell plate, but to the corresponding longitudinal stringer.

2. Stresses in normal service in the region where failure occurred

2.1. *Nature*

Like every vessel, a tanker when passing through a rough sea is subjected to longitudinal bending stresses which synchronize with the periodicity of the waves relative to the vessel.

In addition, the inertia of the liquid cargo, under the same conditions, involves the application to the bulkheads of the tanks of stresses of the same periodicity, which may even acquire shock characteristics.

2.2. *Amplitude and frequency*

The amplitude and frequency of the stresses thus produced depend on the state of the sea. No steps were taken to determine their values, either in the area of the midships frame of the vessel, or in the areas affected by the damage.

It is, however, known that these values are especially high when the length of the waves is approximately that of the vessel.

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2.3. *Total duration of the application of stresses*

Commissioned in August, 1951, the vessel had a total service period, at the time when the damage was discovered, of 39,560 hours at sea, or about 4 years 7 months.

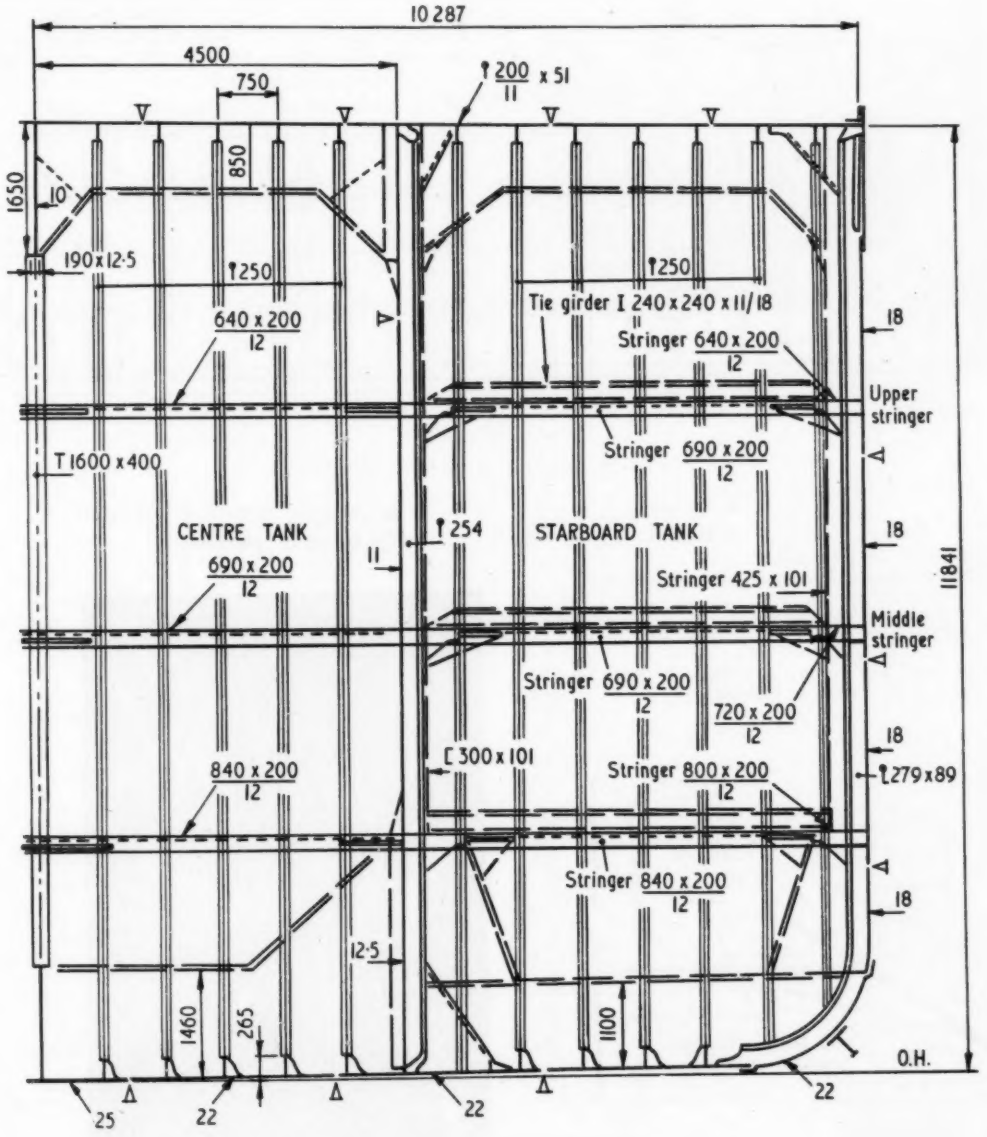
The greatest part of this period was spent on routes where sea conditions were not specially severe. But during the course of the last month's service, which covered a round trip across the Atlantic, the unfavourable conditions mentioned in 2.2 were repeatedly encountered.

3. Information concerning the fractures and the circumstances of their appearance

3.1. *Position of the fractures*

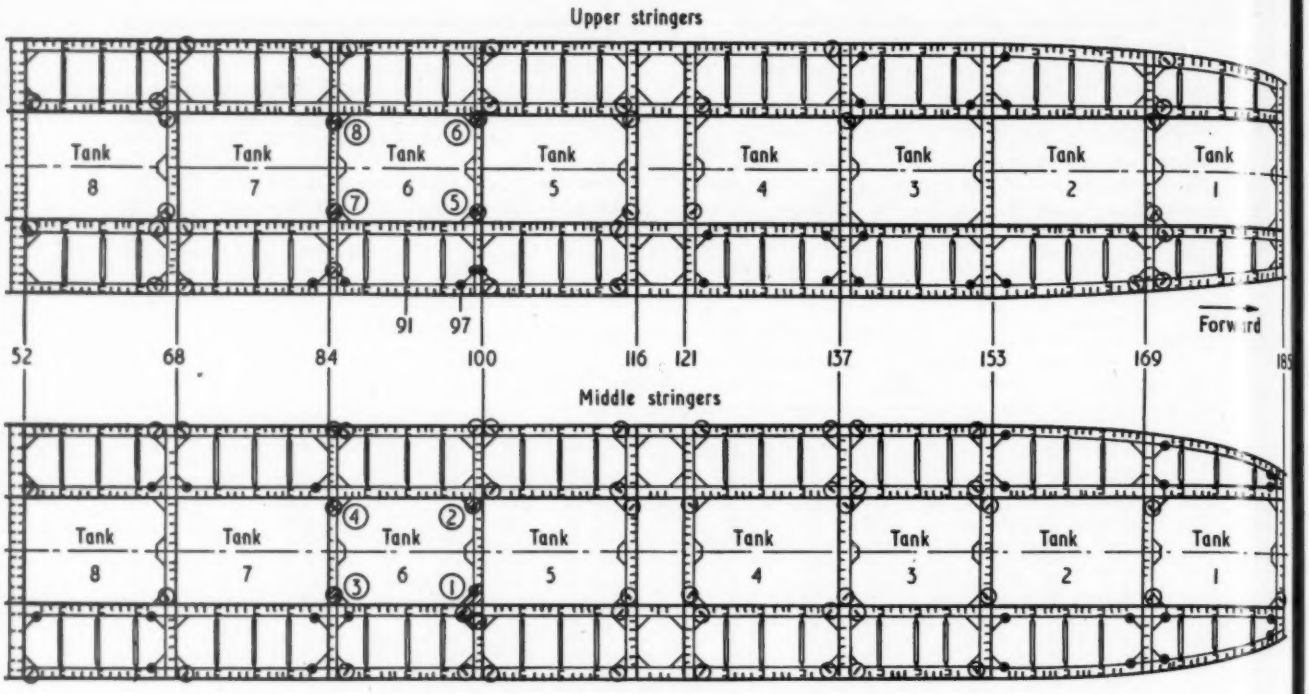
The first damage was observed in April–May, 1957, during the vessel's last trip, when abnormal noises were heard in the region of the aft port tanks.

From the survey which was made in port, after the tanks had been cleaned, it was apparent that the damage consisted of fissures and cracks involving almost exclusively the longitudinal and transverse



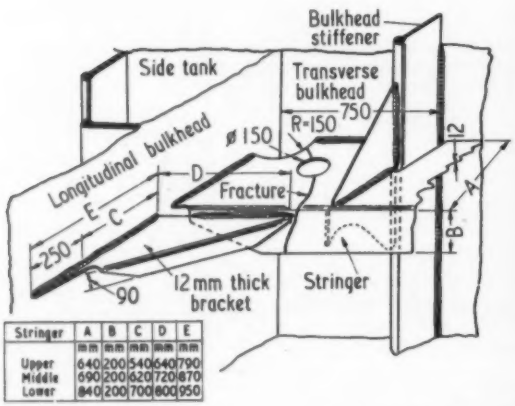
Solid line – Transverse bulkhead and normal frame (C100 and C97)
Dashed line–Web frame and stiffener (C 91)

1—*Half-section amidships*



2—Plan showing location of fractures and fissures

3—Central tank, port corner, seen from aft. Joint between a stringer and the transverse bulkhead ×0·032



Stringer	A	B	C	D	E
	mm	mm	mm	mm	mm
Upper	640	200	540	640	790
Middle	690	200	620	720	870
Lower	840	200	700	800	950

4—Fracture of the middle port stringer aft, of No. C84 transverse bulkhead. (Photograph taken on board after cutting out a specimen) ×0·25

stringers, and especially the middle and upper stringers (Fig. 2).

They were found in the corners of the tanks where they involved the bracket connection between the stringer and the bulkhead (or between corresponding stringers) at the end of the weld between the bracket and the stringer (Figs. 3 and 4). Table I gives details of the fractures and cracks observed.

3.2. *Extent of the fractures*

Eight specimens, taken from the middle and upper horizontal stringers of No. 6 centre tank, were examined in detail in the laboratory.

Table II shows the total lengths of the fractures found in these specimens.

When the fracture reached the circular lightening hole in the web of the stringer, a secondary fracture (or several secondary fractures) commenced in the area lying diametrically opposite on the periphery of the hole.

Table II

Total length of fractures

Stringer	*Forward*				*Aft*			
	Starboard		*Port*		*Starboard*		*Port*	
	No.	*Length* mm	*No.*	*Length* mm	*No.*	*Length* mm	*No.*	*Length* mm
Middle	1	70	2	30	3	300	4	600
Upper	5	720	6	60	7	300	8	860

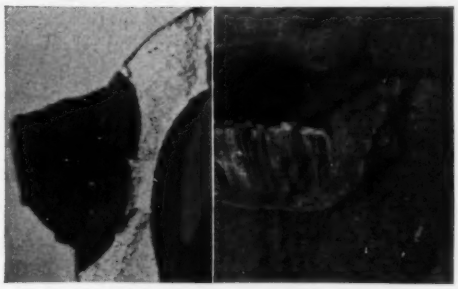
3.3. *Appearance of the fractures*

After opening up and removal of rust, all the fissures and cracks presented the characteristics of fatigue fractures, which originated at the edge of the bracket welded to the flanged edge of the stringer (Figs. 5–8).

Some of the fractures, but not all, were sufficiently old to have suffered, over the initial part of their length, fairly extensive corrosion after the actual fracture.

3.4. *Deductions drawn from the appearance of the fractures concerning the fracture process*

This appearance indicated that the corners of No. 6



5—*Surface of fracture* 6—*Outline of the fracture before opening*

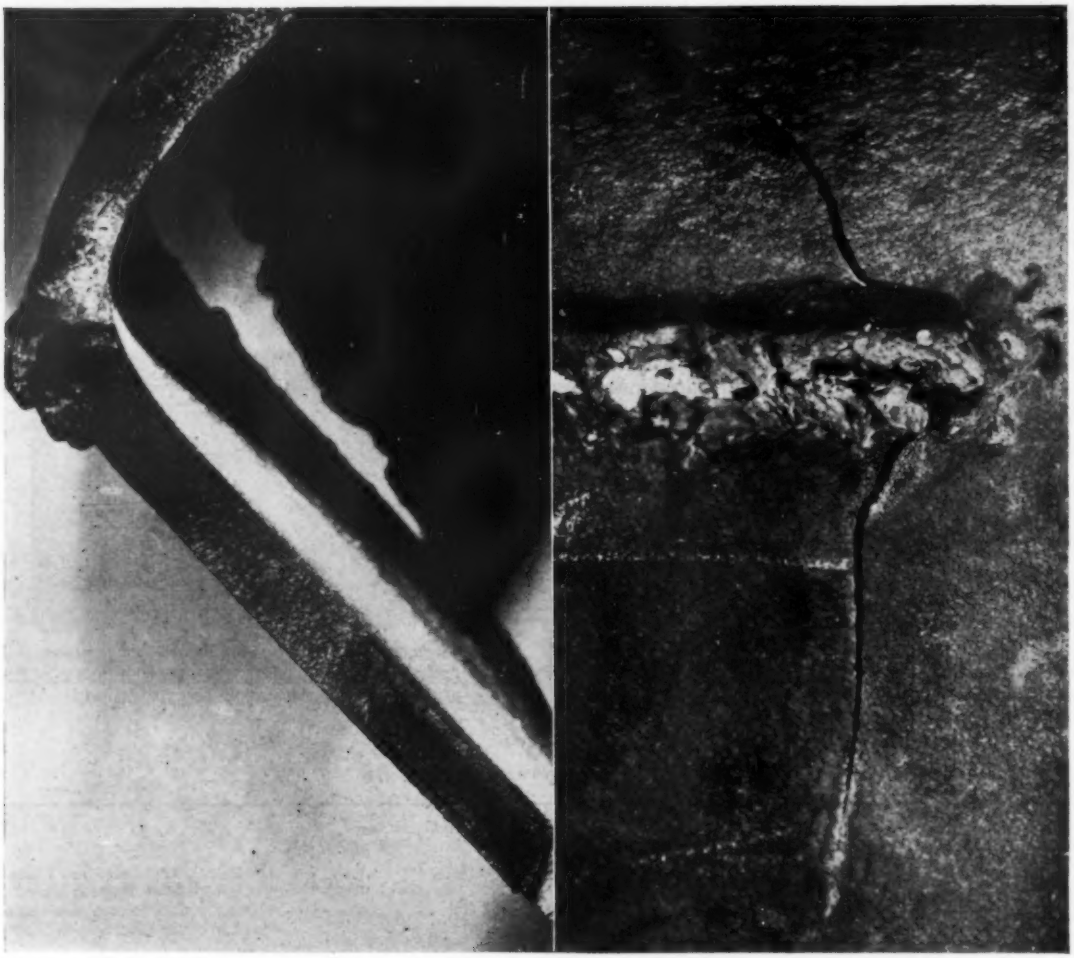
Figs. 5 and 6—*Middle stringer, port forward*

Table I

Summary of fractures and fissures observed

Tank No.	*Position*	*Upper stringers* *Longitudinal*	*Transverse*	*Middle stringers* *Longitudinal*	*Transverse*	*Remarks*
1	Port	2		4 (f)		The letter (f) indicates that a fissure is referred to. A figure is added where this applies only to a certain number of the fractures shown.
	Central				3	
	Starboard	2		4 (f)		
2	Port	2 (f)		2 (f)		
	Central					
	Starboard	3 (2 f)		4 (f)		
3	Port	3 (f)		4		
	Central		1		4	
	Starboard	3 (f)		3		
4	Port	1		3		
	Central		2 (1 f)		2	
	Starboard	4 (f)		4		
5	Port	3		4		
	Central		2		2	
	Starboard	3		3		
6	Port	1		3		
	Central		4		4 (1 f)	Specimens examined in laboratory
	Starboard	2 (f)	2 (1 f)	4 (1 f)	1	
7	Port	2 (1 f)		3 (2 f)		
	Central					
	Starboard	3 (1 f)		3 (2 f)		
8	Port	3		3 (1 f)		
	Central		2		1	
	Starboard	3		4 (3 f)		
Total	Port	17		26		
	Central		13		16	
	Starboard	23	2	29	1	
		40	15	55	17	
		55		72		
		127				

Plus two on starboard side on transverse bulkhead C100, bringing the total up to 129.



7—*Surface of fracture* 8—*Outline of the fracture before opening*

Figs. 7 and 8—*Middle stringer, starboard aft* ×1

centre tank had been strained in a cyclic manner tending to open the angle.

3.5. *Abnormal circumstances which may possibly have accompanied the fractures.*

In this connection there is nothing to add to what has been said in 2.1, 2.2, and 2.3 above.

3.6. *Comments which may be applicable to the behaviour of other identical constructions in service*

This type of damage has not hitherto been found on vessels of the same type.

4. Type of materials in the area of fracture

The whole vessel was constructed in mild steel.

5. Types of welded joints affected

Each fracture traces the outline of the end of a continuous fillet weld attaching a bracket, $\frac{1}{2}$ in. (12 mm) thick, to a stringer.

The welding procedure is not known.

6. Presumed causes of the fracture and lessons which might be drawn from it

Straining the corners of the tanks so as to open the angle can be explained by the effects of inertia of the liquid cargo in the tanks, rather than by the general bending of the whole structure in a swell.

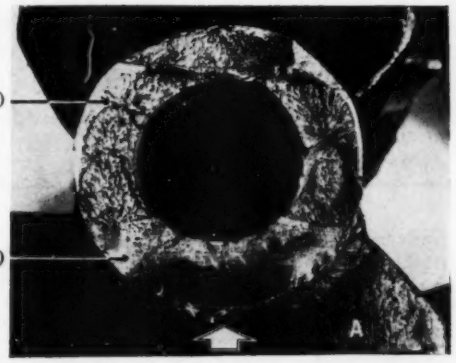
The welded joints between the brackets and the flanged edges of the stringers seem to present a markedly reduced resistance to this kind of stress, perhaps partly because the bracket is not in the same plane as the stringer, and therefore there is a tendency, as the angle becomes more obtuse, for bending of the bracket to occur around its point of attachment.

FRACTURE OF THE AXLE OF A TRAILER

1. Type of construction in which failure occurred

The damage occurred in a trailer axle of 6½ ft (2 m) overall length; the external diameter of the centre part of this axle was 3·85 in. (98 mm) and the internal bore was reamed out to 2·125 in. (54 mm).

Various additional parts were attached, by welding, to the central part of the axle. The welds which were nearest to the ends of the axle were situated a quarter of its total length from the end; these welds attached to the axle two diametrically opposed pads, one centred on the top and one on the bottom of the axle.



2—*Overall view of the fracture:* (*a*) Tear fracture; (*b*) fracture through progressive fatigue cracking ×0·44

2. Stresses in normal service in the region where failure occurred

2.1. *Nature*

The broken axle neither transmitted nor received any torque. It was merely under stress as a result of the load caused by the weight of the truck and the reactions from the wheels.

If, for a given loading of the truck, the first of these loads was fixed, the second depended on the state of the ground over which the truck ran.

2.2. *Amplitude and frequency of the variable component of the load*

No indications are available, experimental or otherwise, concerning the amplitude or the frequency of this fluctuating component.

2.3. *Total duration of application*

The complete fracture of the axle occurred after 4 months in service, but it is impossible to determine accurately the number of hours of actual operation during this period.

3. Information concerning the fracture and the circumstances of its appearance

3.1. *Position of the fracture*

The fracture propagated through the axle level with the outside welds of the pads (Fig. 1).

3.2. *Extent of the fracture*

The fracture affected the whole cross-section of the axle which was completely severed.

3.3. *Appearance of the surface of the fracture*

The surface of the fracture consisted of two regions with quite different characteristics (Fig. 2).

3.3.1—One of these regions, the fine grain of which was characteristic of progressive cracking under cyclic loading (fatigue), covered only about a third of the total area of the fracture, at the bottom of the axle cross-section.

In this zone may be seen a large number of frontal lines, approximately horizontal and with a curvature which is generally very slight, as well as some radial dislocations, particularly in close proximity to the bottom surface of the axle.

3.3.2—The other region presented the characteristics of semi-brittle fracture, with several distinct focal points, giving rise to chevron markings, partially fringed with lips and chamfers.

3.4. *Deduction drawn from the appearance of the fracture concerning the fracture process*

The area of semi-brittle fracture developed after the area of progressive cracking; the first focal points of the shear fracture formed on the boundary of the progressive cracking.

The progressive cracking started in the lower part of the axle cross-section, along the weld seam. It developed approximately symmetrically in relation to the vertical plane passing through the axis of the pad.

3.5. *Abnormal circumstances which accompanied the failure*

No abnormal circumstance has been indicated which could explain the failure. Moreover, the

Table I
Chemical Analysis

C, %	*Mn*, %	*Si*, %	*P*, %	*S*, %
0·28	1·33	0·35	0·02	0·029

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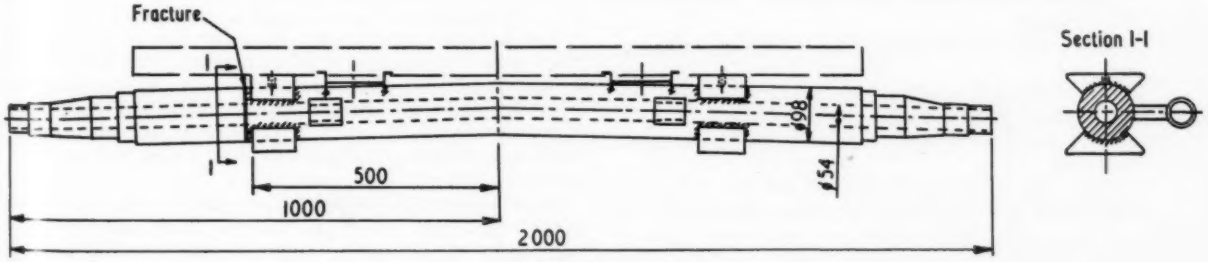


1—*Trailer axle* ×1/13

Table II

Mechanical Properties

Yield Point		*Tensile Strength*		*Elongation* ($k=5{\cdot}65$)	*Reduction in Area*	*Mesnager Impact Strength*
tons/sq.in.	*kg/mm²*	*tons/sq.in.*	*kg/mm²*	%	%	*kgm/cm²*
26·6	42	43	68	24	61	8

presence of numerous frontal lines indicates that the progressive cracking extended over a fairly long period

3.6. *Behaviour of identical structures in service*

Fractures have never occurred in other axles of the same type which did not incorporate a part welded to the bottom surface of the axle.

4. Type of materials in the area of fracture

The principal chemical and mechanical data concerning the steel from which the axle was made are given in Tables I and II.

The chemical analysis was carried out on that part of the axle in the vicinity of the fracture.

5. Type of welded joint affected

The weld along which the fracture was initiated was the fillet weld joining the extreme transverse face of the pad to the cylindrical surface of the axle.

The welding conditions are not known. It is noticeable, however (Fig. 2), that the direction in which the seam was welded changes precisely in the vicinity of the bottom of the axle, which was the point at which the welding was started.

6. Presumed causes of the fracture and lessons which might be drawn from it

The presence of a fillet welded attachment, for a clamping point in the tension zone of the axle, is unfortunate.

FRACTURE OF A DRIVE SHAFT, SURFACED BY WELDING, OF A ROLLING MILL REDUCTION GEAR

1. Type of construction in which failure occurred

The fracture occurred in a drive shaft of a rolling mill reduction gear. This shaft had a diameter of 6·69 in. (170 mm) in the area affected, and a roller bearing was fitted at the position of fracture.

2. Stresses in normal service in the region where failure occurred

2.1. *Nature*

Such a shaft works mainly under rotational bending stresses.

2.2. *Amplitude and frequency of the variable component of the stresses*

The stresses operating on the shaft were not measured.

The shaft was coupled direct to the reversible rolling mill driving motor, on which the number of reversals was from 3,000 to 5,000 per day. The motor attained in about 1 second its full speed of 320–340 revolutions per minute and it stopped likewise in 1 second, which implies considerable torque on the shaft.

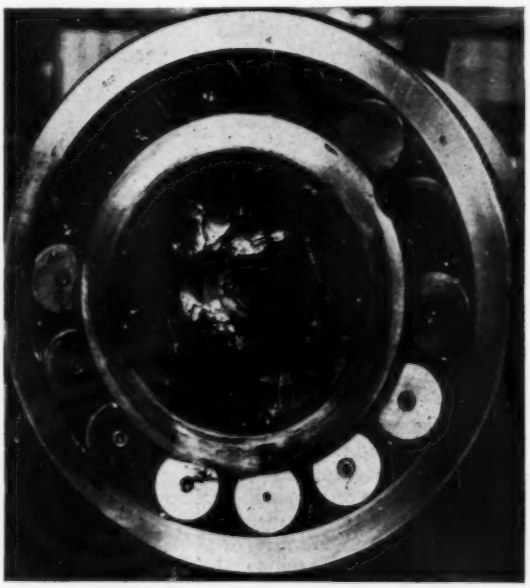
2.3. *Total duration of the application of the stresses*

The shaft operated for nearly 20 days after surfacing by welding.

3. Information concerning the fracture and the circumstances of its appearance

3.1. *Position of the fracture*

The fracture severed the shaft level with the roller bearing (Fig. 1).



1—*Appearance of the fractured cross-section*

3.2. *Extent of the fracture*

The fracture covered the whole of the cross section of the shaft, which was completely severed.

3.3. *Appearance of the surface of the fracture*

The fracture surface was relatively uneven in an inner area, which was somewhat eccentric and which corresponded to the final rupture. In contrast, outside this inner area the fracture was in general smooth and of fine grain (Fig. 2), apart from a limited number of more or less marked dislocations, which were radially orientated (Fig. 3).

These dislocations separated zones of progressive fatigue cracking, which all started from different origins. In each of these zones, it was possible to observe (Fig. 2) a system of faintly defined frontal

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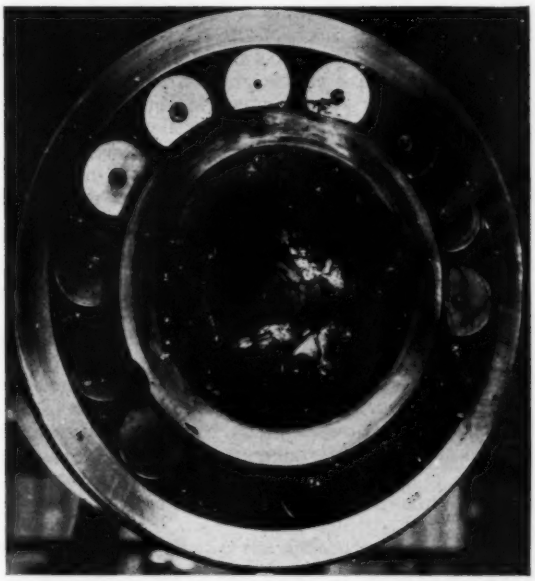


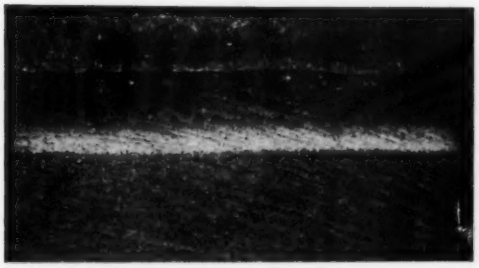
2—*Detail of the fractured cross-section* ×2·1

3—*Detail of the fractured cross-section* ×0·7

lines, which were centred on points situated at about $\frac{5}{64}$ in. (2 mm) from the outer surface of the shaft. The texture of the metal was notably different (as a whole more coarse grained) in a surface layer of about $\frac{5}{64}$ in. (2 mm) in depth.

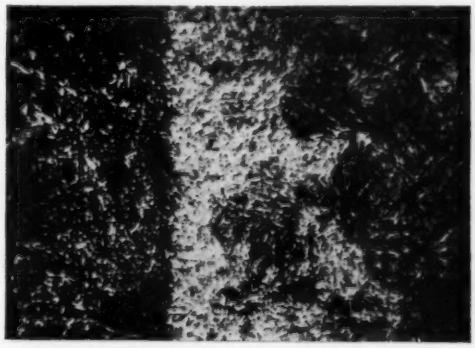
3.4. *Deductions drawn from the appearance of the fracture concerning the fracture process*

The damage was clearly caused by fatigue fracture, apparently connected with the rotational bending stresses. Working on this hypothesis, however, it still remains to be explained why there were several points of origin of the fracture, all situated about $\frac{5}{64}$ in. (2 mm) below the surface.



Deposited metal HV = 270
Heat-affected zone HV = 520
Carbide concentration HV = 420
Unaffected metal HV = 240

4—*Cross-section of a segment. External surface and sub-surface zones* ×4·2



Deposited metal Heat-affected zone

5—*Detail of Fig. 4* ×140

Table I
Chemical Composition

C, %	*Mn*, %	*Si*, %	*Ni*, %	*Cr*, %	*Mo*, %	*V*, %	*Sn*, %	*Cu*, %	*S*, %	*P*, %
0·38	0·84	0·31	1·07	0·84	0·18	Nil	0·03	0·05	0·01	0·029

Table II
Mechanical Properties

Yield Point		*Tensile Strength*		*Elongation* ($k=5{\cdot}65$)	*Reduction in Area*	*Mesnager Impact Strength*	
tons/sq.in.	*kg/mm²*	*tons/sq.in.*	*kg/mm²*	%	%	*kgm/cm²*	*Remarks*
36	57	48·8	77	20	61	9	At about 0·4 in. (10 mm) from the external surface
33·6	53	47	74	21	64	14	Halfway to the centre of the shaft
33	52	45·7	72	20	61	14	In the centre of the shaft

3.5. *Abnormal circumstances which accompanied the failure*

No abnormal circumstances occurred during the 20 days of operation after surfacing.

4. Type of materials in the area of fracture

The principal chemical and mechanical data concerning the steel from which the shaft was made are given in Tables I and II.

5. Type of welded joint affected

The abnormal distribution of the origins of the fracture (*cf.* sections 3 and 4 above) provided a reason for examining the microstructure by photographing segments of the end face of the shaft (Figs. 4 and 5).

It will be seen that the surface layer of $\frac{5}{64}$ in. (2 mm) is formed by surfacing by welding. The deposited metal shows a globular, pearlitic structure, interspersed with free ferrite. Below this layer, the metal of the shaft was affected to a depth of about $\frac{5}{64}$ in. (2 mm) and presents an acicular, troosto-martensitic structure. Beyond this heat-affected zone, a concentration of carbides may be seen, before the unaffected base metal, with a coarse grain structure formed of pearlite interspersed with small pockets of free ferrite, is reached.

The welding procedure for the surfacing is not known. Furthermore, the thickness of $\frac{5}{64}$ in. (2 mm) only represents the residue of the deposited metal after the shaft had been machined; the overall thickness of the deposited layer is unknown.

6. Presumed causes of the fracture and lessons which might be drawn from it

This fracture once again draws attention to the risks to which the surfacing of a relatively hard steel may give rise as regards the fatigue strength of the surfaced part, and it also provides justification for the systematic experiments which have been undertaken on this subject by Commission XIII—Fatigue Testing.

ENQUIRY ON FATIGUE FAILURES

Commission XIII: Fatigue Testing

In Volume 1, No. 11 of *BWJ* (November 1954), we published a note from Commission XIII of the IIW asking for information on cases of Fatigue Failures in Service in Welded Constructions; this note was accompanied by a questionnaire setting out the information which the Commission required for its study of this subject. This enquiry, replies to which have been treated with strict anonymity, has resulted in the receipt by Commission XIII of a steadily increasing number of reports on Fatigue Failures from many parts of the world: much valuable information has been learned from these reports, many of which have been issued by IIW for publication, some of them appearing in the *British Welding Journal*.

With the agreement of the Governing Council of the IIW, Commission XIII is now extending its enquiry on Fatigue Failures in Service in Welded Constructions to cover the allied processes (building-up, flame cutting, flame heating, brazing, metal spraying, etc.). We print below a questionnaire showing the information required by the Commission in reports of Failures.

There is no need to underline that full information about cases of Fatigue Failure is an essential foundation for Commission XIII's work in attempting to define the conditions under which structures should be fabricated so as to give the highest fatigue strength. Readers who are in a position to furnish reports on Failures will, therefore, be doing a most useful service if they will prepare them in the form of replies to Commission XIII's questionnaire and send them to the British delegate on Commission XIII; Mr. R. P. Newman, British Welding Research Association, Abington Hall, Abington, Near Cambridge. The provenance of reports which are not sent to Mr. Newman anonymously will not of course be revealed.

Questionnaire

(1) Type of construction in which failure occurred

(2) Stresses in normal service in the region where the failure occurred. (Indicate whether the stresses are the calculated stresses on which the design of the structure was based, or whether they were measured)
- (2.1) Nature of stresses
- (2.2) Amplitude and frequency of the alternating stress present
- (2.3) Total time of application

(3) Information concerning the fracture and the circumstances in which it appeared
- (3.1) Position of the fracture (or fractures)
- (3.2) Length of the fracture (or fractures)
- (3.3) Appearance of the surface of the fracture (or of each of the fractures) after the complete separation of the fractured faces, if this did not occur at the time of the accident. (Note here any characteristics making it possible to decide whether the fracture was caused by fatigue: presence or absence of deformation, grain of the fractured surface, microfractography, etc.)
- (3.4) Observations on the actual process of fracture deduced from its appearance (probable starting point, etc.)
- (3.5) Any abnormal circumstances which might have accompanied the accident (external temperature, exceptional stresses, etc.)
- (3.6) Any other observations about the behaviour in service of other identical structures

(4) Composition of the materials in the region where failure occurred

(5) Nature of the operation carried out in the region where failure occurred (welding, building-up, flame cutting, flame heating, brazing, metal spraying, etc.) Conditions in which this operation was carried out

(6) Presumed causes of the accident and lessons which might be drawn from it. (It is desirable that those answering the questionnaire should state under this item the results obtained from fatigue tests on experimental components of the same design or of modified design)

(7) Appended documents: plans, sketches, photographs, etc.

INTERNATIONAL INSTITUTE OF WELDING

Reports of Commissions – 1960

Chairmen's reports of the activities of Commissions of IIW following the Annual Assembly held in Liège from 13th to 17th June 1960.

Commission I: GAS WELDING AND ALLIED PROCESSES

(*Chairman—Dr. C. G. Keel*—Switzerland)

Commission I, "Gas welding and allied processes", met four times at the IIW assembly held in Liège from 13th to 17th June 1960. Some forty delegates, experts and observers attended these meetings.

At present, the Commission is made up of 75 delegates, experts and observers from 26 countries.

Sub-commission IA "Brazing and surfacing"

Sub-commission IA, "Brazing and surfacing", which met three times during the year, submitted three documents, namely, document IA–152–60 "Proposed testing methods for the symbolization of filler metals used in brazing" (IIS/IIW–63–60—ex doc. I–137–60), document IA–153–60 "Statistical interpretation of the results of tests for the symbolization of filler metals used in brazing" (IIS/IIW–64–60—ex doc. I–138–60) and document IA–154–60 "Draft code of symbols for filler metals used in brazing" (IIS/IIW–65–60—ex doc. I–139–60). In these three documents, Sub-commission IA proposed a testing method and a new test-piece for use in the symbolization of filler metals used in brazing; this new test-piece was selected from several featured in the relevant literature. The Sub-commission has also studied the problem of the statistical interpretation of these tests and it is clear, from this research, that a smaller number of tests (for example between five and ten) is sufficient for the interpretation of the results. These proposals led to the establishment of the first draft code of symbols for filler metals used in brazing. In a resolution, adopted by the Governing Council, the Commission recommended the publication of the three documents prepared by the Sub-commission, so that the opinions and suggestions of all those concerned might be obtained before the documents are transmitted to ISO.

The Commission decided to inform the "Brazing Committee" of the American Welding Society of these arrangements, to promote an exchange of views at the next meeting, in 1961, in New York. Also in connection with the problems of symbolization, the Commission having heard its Chairman's report on the present position concerning the overall considerations relating to symbolization of all types of filler metals and electrodes used in welding, adopted a resolution emphasizing firstly the importance of a general method of symbolization from the point of view of the work in hand within the Commission and, secondly, expressing the hope that document SST–222–59 "Memorandum on the symbolization of filler metals for surfacing prepared in agreement with the Chairmen of Commissions I, II "Arc Welding", VII "Standardization" and XII "Special arc welding processes", 29th June 1959) will remain valid as a guide to future work.

Sub-commission IB "Oxygen cutting"

Sub-commission IB "Oxygen cutting" submitted document IB–223–59 "Normal oxygen cutting of steels—notes on preheating". The discussion centred mainly on the question of the carbon equivalent formula; after full discussion, it was decided to re-examine the matter with Commission IX "Behaviour of metals subjected to welding".

The Commission examined document IB–224–59 "Questionnaire relatif à la précision en oxycoupage mécanique" (Questionnaire concerning the accuracy of mechanized oxygen cutting). It was decided that this document should be completed and subsequently sent to each member of the Commission. Replies should be returned, at the latest, three months after receipt of the questionnaire.

The Commission then proceeded to discuss document IB–226–60, "Quality assessment of oxygen cutting", submitted by the Soviet delegate, Mr. Chachkov, as a reply to document IB–224–59 with a view to making known the Soviet delegation's opinion on this question. The Sub-commission will study this document and will report on it to Commission members at the next meeting.

Sub-commission IC "Metal-spraying"

Sub-commission IC "Metal-spraying" informed the Commission of the preliminary results of its inquiries. A document relating to metal spraying standards in use in the various countries will be prepared for the New York meeting.

Working Group ID "Definitions of welding procedures"

Working Group ID "Definitions of welding procedures" submitted documents ID–402–59, "Comparative examination of gas welding procedures used in various countries", ID–403–60, "Comparative examination of gas welding procedures used in various countries for non-ferrous metals" and ID–404–60, "Welding procedures for the assembly of plastics". The Commission discussed these documents and decided to complete them. The Working Group was asked to try to define a welding procedure which would be common to all the member countries, account being taken of the information provided by the various member countries. A report on this subject will be prepared for the New York assembly. A decision will then be made as to whether research into a common procedure should be continued or whether

documents ID–402–59, ID–403–60, and ID–404–60, which will probably be completed in the meantime by the addition of information regarding the welding of lead, brass etc., should be published.

Working Group IE "Oxy-acetylene pressure welding"

Working Group IE "Oxy-acetylene pressure welding" re-examined the following three documents: IE–505–59, "Questionnaire concerning gas-pressure welding", I–142–60 (IE–506–59), "List of publications on gas pressure welding" and IE–507–60, "The present state of development and application of gas-pressure welding in the member countries of the IIW". Document I–142–60 was the subject of a resolution, adopted by the Governing Council, to the effect that it should be transmitted to Commission IV "Documentation" for information and possible recommendation for publication. Document IE–507–60 will be discussed again next year after its completion; document IE–510–60, "Report on the plans of Working Group IE for the next period" was approved.

Working Group IF "Gas welding equipment"

Working Group IF "Gas welding equipment" asked Mr. Zorn (Germany), Vice-Chairman, to act as Chairman for the current year, since Mr. Sznerr (Poland) is unable to undertake this task. The Commission decided that there were grounds for examining in the first place, welding and cutting blow-pipes. A questionnaire in this connection will be sent to member countries to ascertain what aspects should be the subject of standardization.

On Wednesday, 15th June 1960, the Commission organized, under the Chairmanship of Dr. Keel, a *colloquium on metal-spraying* which was most successful. Thirteen papers were presented on this occasion. A large number of participants attended the colloquium and a lively discussion took place; the Chairman wishes to thank all the authors and Mr. Herpol (Belgium), *rapporteur*, very warmly for the extremely useful work they accomplished. At this colloquium the Commission's attention was drawn to the teaching of metal spraying, by means of three reports on this subject; a resolution was adopted, and subsequently approved by the Governing Council, asking that Commission XIV, "Welding Instruction", should examine these three documents. Moreover, as a result of the interest raised by this colloquium, the Commission put forward a resolution, which was transmitted to the Executive Council by the Governing Council, asking that annual colloquia should be arranged in the future and suggesting that the theme for the next should be on the subject of "brazing".

The meetings of Commission I, in Liège proved very fruitful thanks to the efficient work of the Sub-commissions and Working Groups and the understanding and co-operation of those who attended the discussions; thanks and congratulations are also due to the Belgian bodies who were responsible for organizing the assembly.

Commission II: ARC WELDING

(*Chairman—Prof. Ir. H. E. Jaeger*—Netherlands)

At the annual meeting the chair was taken by the Vice-chairman, Ir. A. Mudde (Netherlands), the Chairman being unable to attend the meeting, due to ill health.

Since the 1959 Annual Assembly, which was held in Opatija, Yugoslavia, evidence of the activity of the Commission has been provided by various meetings of its Sub-commissions, held as follows:

Sub-commission A (Effect of hydrogen in weld metal)
6th October 1959 in Paris
22nd February 1960 in Eindhoven (Netherlands)

Sub-commission B (Testing and measurement of arc welding equipment)
25th February 1960 in Eindhoven (Netherlands)

Sub-commission C (Testing and measurement of weld metal)
7th October 1959 in Paris
23rd February 1960 in Eindhoven (Netherlands)

Sub-commission D (Deep penetration welding)
8th October 1959 in Paris
26th February 1960 in Eindhoven (Netherlands)

Sub-commission E (Classification of electrodes)
8th October 1959 in Paris
26th February 1960 in Eindhoven (Netherlands)

The meetings of Commission II during the Liège Assembly were attended by 15 delegates, 36 experts, and 19 observers, totalling 62 persons from 20 countries.

The 33 documents studied fall into the following categories:

3 Sub-commission A documents
5 Sub-commission B documents
5 Sub-commission C documents
10 Sub-commission D documents
4 Sub-commission E documents
1 document from the Working Group "Productivity by arc welding"
5 documents about subjects not yet dealt with by Commission II.

I. SUB-COMMISSION A—EFFECT OF HYDROGEN IN WELD METAL

(*Chairman—Dr. N. Christensen*—Norway)

1. The main points arising out of the annual report of the Sub-commission (Doc. II–118–60) are:

1.1 Methods for defining "H" electrodes (electrodes with weld metal having an extra low hydrogen content)

During the course of the year the Sub-commission succeeded in establishing a method of determining the water content of the covering of a low hydrogen electrode, based upon a fairly satisfactory concordance of the results obtained in seven IIW member countries. Work on the correlation between the water content and the hydrogen content and the tendency to cracking has been started. Valuable information has come from Japan and the United Kingdom.

1.2 The role of hydrogen in acceptance testing of electrodes

Results obtained so far indicate that the maximum density of microfissures does not appear at the highest cooling rates. At present no quantitative account of this work can be given. More information will be collected with a view to a future proposal for the classification of electrodes on the basis of this criterion.

1.3 Temporary deterioration of the mechanical properties of weld metal due to hydrogen

Commission II adopted a resolution, which was approved by the Governing Council, to publish doc. II–113–60: C. Pfeiffer (Sweden) "The influence of the storing time on tensile test bars of all weld metal".

1.4 Non-metallic inclusions in weld metal

As a preliminary conclusion of the metallographic study of non-metallic inclusions, it appears that inclusions readily observed by common optical methods amount to only approximately 10% of the total content of such inclusions.

A contribution of the Japanese delegation (Doc. II–143–60, "Non-metallic inclusions in weld metal") will be discussed in the year 1960–61.

2. Other work

At the request of the USSR delegate, doc. II–114–60, "Bibliographie sur la question de la physique fondamentale de l'arc électrique" (Bibliography on the question of the fundamental physics of the electric arc) was submitted. This document has been handed over to Sub-commission A, for study together with the Japanese report, doc. II–145–60, "Physical properties of slags from mild steel arc welding electrodes". Sub-commission A will first decide whether to take on these new subjects and extend its terms of reference, or whether to advise Commission II either to establish a new Sub-commission or not to take on the study of new subjects.

II. SUB-COMMISSION B—TESTING AND MEASUREMENT OF ARC WELDING EQUIPMENT

(*Chairman—A. Gaubert*—France)

The main points arising out of the annual report of the Sub-commission (Doc. II–156–60) are:

1. Definition of the suitability for welding of different equipment

1.1 Interesting results were obtained by a rotating commutator, giving a constant ratio of duration of short circuit to the duration on load using a rectifier and a battery of accumulators in order to determine the coefficient r, ρ and R_2 $V10$. Complementary tests will be undertaken by Messrs. Besson (Switzerland), Carrer (Italy), and Girardi (Italy) with a variable duration of short circuit.

1.2 Using eight generators of known dynamic characteristics, qualified operators have formed an opinion after welding pipes with cellulosic electrodes and building up with tubular electrodes. The opinion they expressed was in agreement with the previous classification.

1.3 According to Messrs. Kocher (Switzerland) and Ruetschi (Switzerland) the dynamic voltage *Ud* depends on the working conditions from which the voltage is re-established. The tests carried out by Messrs. Carrer and Girardi confirm that *Ud* is a decreasing function of the duration of the short circuit. The values of *Ud* for 0·015 seconds (time of transfer of one droplet) could represent a criterion of the suitability for welding. Messrs. Kocher and Ruetschi have indicated that an acceptable limit for *Ud*=40 V.

Only one of the generators studied does not correspond to this criterion.

1.4 Tests carried out on four transformer-rectifiers lead to the conclusion that this type of apparatus is of at least the same quality as the best of the eight generators tested.

1.5 According to preliminary tests by Mr. Besson and Mr. Gerretsen (Netherlands), a high level of 3rd harmonic, showing itself in the current wave as a slow build-up from 0; is undesirable from the point of view of arc stability of a single phase welding transformer. Tests will be continued to establish a criterion, expressed as a coefficient of ease of welding.

2. Admissible current for welding cables

Proposals are presented in doc. II–136–60, "Tests with a view to defining the admissible currents in welding cables and proposed values" (IIS/IIW–59–60) applicable to cables insulated with polychloroprene. Commission II adopted a resolution, which was approved by the Governing Council, to publish this document, and to transmit it to the Committee of Experts No. 1 "Safety requirements for electric welding equipment" of Committee 26, "Electric welding" of the International Electrotechnical Commission (IEC).

3. Safety in arc welding

Commission II adopted a resolution, which was approved by the Governing Council, to publish doc. II–137–60, "Memorandum on low voltage safety devices" (IIS/IIW–60–60), concerning low voltage safety devices. Further work is hampered because various delegations have not yet transmitted to Sub-commission B the text of their national regulations relating to safety in arc welding. The proposals of the IEC (Committee 26) concerning, on the one hand, the earthing of welding equipment and circuits and, on the other, tests for the dielectric rigidity of welding equipment, are considered to be acceptable.

4. Other work

In reply to a question from the Committee of Experts No. 1 of Committee 26 of the IEC, Commission II drafted the following resolution, which was approved by the Governing Council (resolution 3): "In general, the maximum open circuit voltage of welding equipment for use with covered consumable electrodes on d.c. and a.c. varies according to applications and between countries from 70 to 120 V."

The other questions included in the working programme of this Sub-commission, have not given rise to important developments during the past year, and appear again in the working programme for next year.

III. SUB-COMMISSION C—TESTING AND MEASUREMENT OF WELD METAL

(*Chairman—Dr. U. Girardi*—Italy)

The following subjects were dealt with in the annual report of this Sub-commission (Doc. II–121–60):

1. Study of the impact values of weld metal at sub-zero temperatures

The distribution curve of the experimental values of the Charpy V-notch impact test was studied at different temperatures from a statistical point of view.

A wide programme of research was carried out in France, Germany, Italy, the Netherlands, and Sweden. A complete report of the tests is given in doc. II–122–60, "Results of the research which has been carried out on the statistical distribution of impact values of weld metal at low temperature". Commission II adopted a resolution, which was approved by the Governing Council, to publish this document. For the acid, cellulosic and rutile types of electrode tested, the transition curve showed a practically normal distribution, whereas the basic covered electrodes showed a more or less pronounced bimodality in the transition zone. Due to the bimodality the standard deviation is rather high.

Tests carried out with different criteria in Belgium (Doc. II–C–68–60) and in Japan (Doc. II–141–60) confirmed the high degree of scatter already observed. The Swiss delegate will carry out Schnadt tests with the same electrodes as those used by Sub-commission C.

2. Study of the hot-cracking phenomenon in weld metal

Doc. II–142–60, K. Nakane, T. Muramoto, "Study on the reverse bend severity weldability test: A modified Murex hot-cracking test", forwarded by the Japanese delegate, will be studied next year. Doc. II–58–59, H. Suzuki, K. Ishizaki and A. Oishi (Japan) "On the fisco type cracking test for austenitic stainless steel electrodes" was recommended for publication. A resolution to this effect was approved by the Governing Council.

IV. SUB-COMMISSION D—DEEP PENETRATION WELDING

(*Chairman—J. G. Daivier*—Belgium)

In his annual report (Doc. II–154–60) Mr. Daivier gave a survey of the different chapters of the "Code of Practice" for the use of deep penetration electrodes. Work on this Code has not yet been concluded and will be continued.

It was decided that Sub-committee D would study the desirability of changing the character of its work. In the future, this could perhaps deal with "Methods of manual arc welding". Under the new programme the Japanese doc. II–146–60, "Investigation on the practical application of 'Uranami' (back wave) welding", will be studied.

V. SUB-COMMISSION E—CLASSIFICATION OF ELECTRODES

(*Chairman—Dr. E. Kauhausen*—Germany)

The annual report II–155–60 describes the difficulty which Sub-commission E has encountered in connection with doc. SST–222–59, "Memorandum on the symbolization of hard surfacing filler metals". This document was prepared at Opatija in collaboration with the Chairmen of Commissions I, II, VII, and XII.

Sub-commission E was not able to follow the general scheme laid down in this document for the symbolization of all kinds of filler materials. The principal difficulty concerns the order of the symbols. All the delegates, with the exception of the French one, agreed that the first symbol of the general scheme should be the symbol for the welding process.

Doc. II–127–60, "Code of symbols for filler metals used in hard-surfacing electrodes" has been amended in accordance with the wishes expressed in doc. SST–222–59, except as regards the order of the symbols. Commission II adopted a resolution to forward doc. II–127–60 to ISO/TC 44/SC 3 (Welding—filler materials and electrodes), and pointed out in this resolution that a uniform general scheme should first be established by the ISO, before any discussion takes place on doc. IIS/IIW–33–59 (ex Doc. I–108–59), "Draft code of symbols for filler metals used in gas surfacing" (which has already been forwarded to ISO by Commission I, "Gas welding and allied processes") and on doc. II–127–60.

This resolution was adopted by the Governing Council, account being taken of the resolutions of Commission I (Gas welding and allied processes) and VII (Standardization) on this subject.

VI. WORKING GROUP—PRODUCTIVITY IN ARC WELDING

(*Former Chairman—R. Butler*—United Kingdom)

The Chairman of the Working Group resigned last year. In general it was felt that no one was particularly interested in the work of this Group. It was therefore decided that Mr. Mudde, Vice-Chairman of Commission II would prepare a final report in which the Japanese document, doc. II–120–60 (answer to a former questionnaire), would be included.

VII. WORKING PROGRAMME FOR THE YEAR 1960-1961

Commission II and its Sub-commissions will study the following questions:

Sub-commission A

(1) Methods for the definition of "H" electrodes.
(2) The role of hydrogen in acceptance testing of electrodes.
(3) Temporary deterioration of mechanical properties.
Item (4) of the previous programme: "Non metallic inclusions in weld metal" will be extended to cover aspects other than that of interaction with the hydrogen present in the weld metal.
(5) The effect of tempering at 250°C. upon the hydrogen content of weld metal.

In accordance with the decision taken by Commission II, the Sub-commission will discuss, at its next meeting, methods of handling various fundamental problems not covered by any of the existing Sub-commissions, *e.g.* arc physics.

Sub-commission B

(1) *Definition of the suitability for welding of different equipment*

(*a*) Experimental work for the practical determination of the coefficients r and ρ by using a storage battery and rectifiers for the re-establishment of the voltage. Influence of the duration of short-circuits on the value of the two criteria.

(*b*) Comparison of coefficients r, ρ and R_2 $V10$.

(*c*) Investigation on the advantages of the integration of $V10$ by re-establishment of the voltage from normal welding conditions.

(*d*) Further study on the incidence of the dynamic behaviour of welding generators on the variation of the penetration.

(*e*) Further study on the correlation between the fusion losses and the current intensity of the dynamic

short-circuit: Influence of the phenomenon of magnetic arc blow.

(*f*) Suitability for welding of single phase welding transformers. Definition of a criterion for the suitability for welding based on a coefficient for the form of current-wave when the transformer is connected to a synthetic load comprising a system of rectifier/accumulators.

(2) *Measurement of arc welding currents and voltages*
Checking of the results obtained with different types of equipment, using electrodes from the same batch.

(3) *Definition and measurement of the flexibility of welding cables*
Tests carried out in accordance with doc. II–30–58 by various investigators.
Study of further proposals.

(4) *Programme for the specification of flexible welding cables*

(5) *Study of doc. II–144–60.* "Effect of hot start for elimination of blow holes and improvement of bead junction."

(6) *Safety in arc welding:*
(*a*) Results of the enquiry on statutory regulations.
(*b*) Means of ensuring liaison with Committee 26 of the IEC.

(7) *Liaison with Sub-committee 4, "Arc welding equipment" of ISO/TC 44 "Welding"*
Enquiry on the specification of rectifiers.

(8) *Problems arising from the connection of single phase equipment to the main power supply*
Study of doc. II–B–29–57, "Détermination des lois expérimentales du papillotement (flicker) en vue de leur application aux réseaux basse tension sur lesquels des charges varient périodiquement ou aléatoirement (soudeuses, démarrages de moteurs)" (Determination of experimental laws governing flicker, with a view to their application to low-voltage circuits on which the loads vary periodically or at random (welding machines, starting of engines)), by P. Ailleret (France); "Dispositifs expérimentaux pour l'étude flicker; résultats des mesures sur les réseaux basse tension" (Experimental devices for the study of flicker; results of experiments on low-voltage circuits) by A. Dejou and P. Gaussens (France).

(9) *Calculation of the power of multi-operator equipment*
Preparation of tables or diagrams expressing the formulae previously established.

Sub-commission C

(1) Establishment of a "conventional" method of acceptance test for the impact properties of weld metal at low temperatures, ensuring a sufficient degree of results.

(2) Establishment of a method of hardness testing for the code of symbols for hard-surfacing electrodes.

(3) Establishment of a method for determining the recovery of an electrode and the weight of metal melted by ampere per minute, adopting as a basis of discussion doc. II–115–60, "A method for determining main characteristics of electrode melting process in arc welding."

(4) Collection of published works and available experimental data concerning the study of brittle fracture in weld metal and the technological and metallurgical factors which could influence the scatter or the distribution of impact values.

(5) Study of the hot cracking phenomenon in mild steel weld metal.

(6) Execution of hot cracking tests in chromium–nickel austenitic weld metal.

Sub-commission D

Further study and drafting of the "Code of practice".
Study of the changes to be made to the programme of this Sub-commission.
Study of doc. II–146–60.

Sub-commission E

(1) Final proposal for a general scheme for the symbolization of all filler metals. A memorandum on the reasons governing this proposal is to be prepared for the IIW observer appointed to attend the meeting of ISO/TC 44/SC 3 "Welding—Filler materials and electrodes".

(2) Discussion on the proposals from the Belgian and Italian delegations on Commission II regarding the symbolization of electrodes for the welding of mild steel (Draft code of symbols ISO Recommendation No. 178).

Commission III: RESISTANCE WELDING

(*Chairman—Dr. H. G. Taylor*—United Kingdom)

1. Attendance

The annual meeting of the Commission was attended by representatives of 16 countries.

2. Meetings of Sub-commissions

Since the 1959 Annual Assembly at Opatija (Yugoslavia), evidence of the activity of the Commission has been provided by various meetings of its Sub-commissions, held as follows:

Sub-commission E, "Productivity": 4th December 1959 at Stuttgart (Germany) and 1st April 1960 at Turin (Italy).

Sub-commission G, "Non-destructive testing of spot welds": 29th January 1960 at Paris.

3. Classification of spot welded joints

Mr. Klopfert (Belgium) presented a document on the classification of spot welded joints (Doc. III–121–60, "Preliminary draft classification of spot welds in mild steel"). He expressed the opinion that, since there is a general view that only one quality of spot welds should be recognized (the highest quality) but that in fact the standard of inspection varies with the service required, the only satisfactory solution was to classify spot welded joints. This view was generally agreed and it was decided to circulate his document to all the member societies and discuss the matter further at the next Assembly in New York.

4. Projection welding

It was reported that a statement on the need for research on groups of projection welds in excess of three in number had been circulated by the Scientific and Technical Secretariat of the IIW, but so far it was

not known what research was in hand. It was agreed again to draw the attention of the British Welding Research Association to the fact that there was serious doubt about the possibility of extrapolating their report (Doc. IIS/IIW–51–60, ex Doc. III–103–58, "Projection welding of low-carbon steel") to more than three spots.

A report was received from Japan (Doc. III–138–60 by Messrs. Nakamura and Hamasaki) on nugget movement, but discussion was postponed until the New York Assembly.

5. Flash welding (Sub-commission C)

Mr. Klopfert presented the third part of his report on flash welding (Doc. III–122–60). This part deals with light alloys and it was agreed to circulate it to all member countries and to invite comments for consideration at New York.

The study of a Japanese report (Doc. III–137–60 by Messrs. Nakamura, Yamaguchi, and Hamasaki) on the subject of flash welding of coils of rolled steel strip was postponed till 1961.

6. Productivity (Sub-commission E)

Mr. Bernier (France) reported (Doc. III–128–60) that this Sub-commission had met several times during the year and that their work was making good progress.

7. Non-destructive testing (Sub-commission G)

The Chairman reported that this Sub-commission had held one meeting and had agreed that certain spot welds should be prepared and tested for defects by all possible methods in various countries.

8. Series welding

Mr. Simmie (United Kingdom) submitted reports (Doc. III–116–60) showing that greater consistency and tip life could be obtained by tying together the secondary leads of series welding transformers. He reported that he had not done any further work on the mutual effect of transformers but he hoped that Dr. Nippes (United States) would investigate this and report at New York in 1961.

9. Hourly output of resistance welding machines

A document (III–131–60) was submitted by the United Kingdom delegation drawing attention to limitations in the French proposals. The French delegation accepted the proposals contained in this document but later requested that instead of inserting, on the basis of IIW publications, the pressure desirable for certain spot welds, the data should be left for the manufacturers to fill in.

This proposal was not generally acceptable and it was resolved that the matter be referred to the manufacturers' associations in the various countries and that replies be sought in time for consideration at New York in 1961.

10. Repair of welded products

A report (III–132–60) was received on welded coaches and other road vehicles from Mr. Bernier and one (III–134–60) from Dr. Gallinaro (Italy) on the repair of light alloy aircraft structures.

After preliminary discussions it was agreed to re-examine this matter the following year when the Italian report would be supplemented by diagrams and the Yugoslavian delegate promised to try to obtain a report on the repair of welded railway rolling stock.

11. Welding primers

Several documents:

Doc.III–115–59 "Bibliography prepared by the Institute of Welding on the spot welding of rust proofed or paint-primed mild steel sheet",
Doc.III–117–60 "Tests on welding primers" and
Doc.III–135–60 "A new type of primer for resistance welding"

were available on welding primers and the Belgian delegation reported on the research which it is doing in this field (Doc. III–127–60, "Couche d'impression de soudage pour la protection des soudures contre la corrosion"—Welding primers for the protection of resistance welds against corrosion). This delegation will collect all the reports together and in due course make a general report.

12. Welding variables

The Belgian delegation reported on developments which have taken place in the measurement of welding variables. This work has been done at Brussels University by Mr. Peretz, with industrial support. The Commission subsequently saw the equipment at the Liège Fair and was impressed with the developments which had taken place.

13. Welding of reinforcing bars for concrete

A Russian report was received on this subject which dealt with various methods applied in the USSR, including friction welding and flash-butt welding. It was decided, in a resolution approved by the Governing Council, to recommend this document for publication (Doc. III–124–60, N. J. Kocanovskij and S. M. Tazba (USSR), "Equipment for welding reinforced concrete pieces").

14. Russian work on resistance welding

The USSR delegation submitted a set of abstracts of documents published in the Soviet Union in the last few years on resistance welding. The Commission felt that this was a very useful document and recommended, in a resolution approved by the Governing Council, that copies be submitted to member countries (Doc. III–125–60, "Abstracts of some scientific works on resistance welding carried out in the Soviet Union in 1957–1958").

15. Surface colouration for assessing spot weld quality

Mr. Bernier described (Doc. III–119–60) production tests which he had made on motor car chassis members to test the Joumat method of weld control by surface colouration. He had found that the method was not practicable because of

(*a*) Variation of steel composition
(*b*) Badly fitting parts giving rise to long "hold" times
(*c*) Deformation of electrode tips.

16. Welding of plastics

For the first time this subject came up at the Commission and was discussed with the aid of a document from Yugoslavia (Doc. III–136–60, "Le classement des

appareils de soudage des matières plastiques"—Classification of welding equipment for plastics).

17. Disbanding of Sub-commissions

It was decided to recommend the Governing Council, which approved the resolution, that the following two Sub-commissions be disbanded as their work was complete:

Sub-commission IIIA—Weldability in Spot Welding.

Sub-commission IIID—Terminology of Electronic Control of Resistance Welding Machines.

Commission IV: DOCUMENTATION

(*Chairman—L. Blosset*—France)

Twelve delegates and experts and one observer representing eight countries took part in the work of Commission IV at the Annual Assembly of the IIW in Liège.

I. BIBLIOGRAPHICAL BULLETIN FOR WELDING

As in the past, the Bibliographical Bulletin for Welding has continued to be prepared as a result of the permanent collaboration of the French publisher and of the regular contributions of certain members of the Commission. A general account of work relating to the Bulletin carried out since the last Assembly (Opatija 1959) appears in the Chairman's 1959–1960 report (Doc. IV–107–60). This report was approved by the Commission at the Liège meetings.

1. Preparation of the Bulletin

Abstracts of literature of the following countries have been regularly prepared by the delegates of those countries: Czechoslovakia, France, Japan, Netherlands, United Kingdom. In addition, the following countries have made a partial contribution: Austria, Belgium, Germany, Italy, Norway, Spain, Sweden, Switzerland, U.S.S.R., Yugoslavia.

The abstracts of the technical publications of the following countries were prepared in whole or in part in France: Australia, Belgium, Canada, Czechoslovakia (until the start of the regular contributions from that country), Germany (three-quarters of its publications), Netherlands, Poland, Roumania, Switzerland, United Kingdom, U.S.A., U.S.S.R. In addition, the French organizations have also abstracted IIW documents not yet published.

Effective participation, starting this year, has been promised by the United States. In addition, greatly increased German collaboration is expected with effect from the third quarter of 1960.

The French organizations continue to be responsible for the translation of the abstracts from English into French or from French into English and for the bilingual publication of the Bulletin including, with the last number of the year, an index of authors.

In the year 1959, 2,408 abstracts were published in the Bulletin. These abstracts were of publications of the following countries (column 1 gives the number of abstracts of publications of each country which appeared in the Bulletin, column 2 that of the abstracts prepared in each country):

	(1)	(2)
Australia	54	—
Austria	13	9
Belgium	75	40
Canada	42	—
Czechoslovakia	312	60
France	236	1654
Germany	165	42
Italy	69	67
Japan	111	110
Netherlands	80	62
Norway	27	27
Poland	28	16
Roumania	16	—
South Africa	7	—
Sweden	33	33
Switzerland	103	62
United Kingdom	201	158
Uruguay	6	—
U.S.A.	391	—
U.S.S.R.	386	68
IIW	53	—
	2408	2408

2. Concordance between the Universal Decimal Classification system and the IIW classification system

The International Federation of Documentation (FID) agreed to draw up a complementary list of the concordance of the two systems with the headings listed in the UDC order, the original list, in the IIW order, having been recommended by the IIW for publication last year. The combined document is at present being seen through the press by the FID; the IIW will meet the printing costs. The work of Sub-commission B of Commission IV being thus completed, the disbanding of this Sub-commission was the subject of a resolution by the Commission; this resolution was adopted by the Governing Council.

3. Addition of new headings to the IIW's Classification Table of Documentation

New headings have been added to the Table to cover tungsten as a weldable metal and various welding processes: slag welding, electron beam welding, plasma welding, ultrasonic welding. In addition, a list of metals which could be of interest from the point of view of welding is to be drawn up and examined each year with a view to adding to the Table metals whose introduction is justified by the amount of literature relating to them.

4. Classification of documentation relating to alloy steels

In accordance with the decision taken in 1959, reports were prepared by Mr. Dobrowolski (Poland) (Doc. IV–102–60 and IV–104–60) and Mr. Hooper (United Kingdom) (Doc. IV–109–60). Various views on this question were put forward by the American, Belgian, German and Dutch delegates (Doc. IV–101–60) and by the Chairman (Doc. IV–103–50).

The conclusion reached by the members of the Commission who were present was that a classification of steels on the basis of their properties and uses would be more likely to result in a distinction which could be made use of in practice than a system based on chemical composition.

A Sub-commission was set up with the task, firstly, of drawing up a list of the properties and tests relevant to the classification of steels with a view to the preparation of such a classification and, secondly, of insuring that the Classification Table of Welding Documentation

is kept constantly up to date. This Sub-commission is composed of Mr. J. Hooper (United Kingdom) Chairman, and Messrs. Bylin (Sweden), du Chesne (Belgium) and van Schaik Zillesen (Netherlands).

5. Circulation of the Bibliographical Bulletin—Budget—Advertising

The subscription rates for the Bulletin were slightly increased in 1960. There is a slight fall in the number of subscribers this year.

The year 1959 closed with a deficit of 3,501,319 old French francs, but this deficit was partially covered by a subvention received from UNESCO through the intermediary of the UATI of 1,225,000 French francs, equivalent to $2,500. The remainder of the deficit, that is 2,276,319 French francs, was carried by the French Institute of Welding. This deficit is a little larger than that of last year because of the general increase in the cost of the Bulletin.

Additional pages of advertising have been booked in 1960 which will slightly increase the income under this heading.

II. EXHIBITION OF PUBLICATIONS FROM VARIOUS COUNTRIES, CONCERNING WELDING AND ALLIED PROCESSES—CATALOGUE

As in previous years, an exhibition of publications was organized this year, under the auspices of the Commission, during the Liège Assembly. Exhibits from 24 countries were included: Australia, Austria, Belgium, Canada, Czechoslovakia, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Poland, Roumania, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, Uruguay, U.S.S.R., Yugoslavia.

The exhibition was organized by the Belgian Delegation of the IIW, which has also agreed to be responsible for preparing the catalogue of publications exhibited for the first time at Liège.

The catalogue of works first shown at Opatija will be combined with the Liège catalogue to constitute the fifth section of the catalogues of IIW exhibitions; taken together these catalogues provide a complete bibliography, brought up to date each year, of literature relating to welding and allied processes.

In accordance with a resolution of the Commission which was adopted by the Governing Council, the documents which the IIW recommends for publication will from now on be shown at the exhibitions, a special binding being used.

III. EXHIBITION OF PHOTOGRAPHS OF WELDED CONSTRUCTIONS AND APPLICATIONS OF ALLIED PROCESSES

As last year, an exhibition of photographs was combined with the exhibition of publications; so that the fullest advantage might be derived from the excellent accommodation provided for the exhibition, there was no limit this year on the size and number of photographs which could be shown.

In a resolution approved by the Governing Council, the Commission congratulated the Belgian Organizing Committee on the very remarkable setting and magnificent presentation of the two exhibitions of publications and photographs. The Governing Council as a whole joined in the thanks expressed by the Commission.

There will be no IIW Exhibition next year at New York; the following exhibition will be held at Oslo in 1962.

Commission V: TESTING, MEASUREMENT AND CONTROL OF WELDS

(*Chairman—Professor G. A. Homès*—Belgium)

Introduction

During the year Mr. D. Kat (Netherlands) has undertaken the duties of Technical Secretary of Commission V and has become a member of Sub-commission A (Radiography).

Mr. Vinter (Denmark) was appointed Chairman of Sub-commission A in succession to the late L. van Ouwerkerk (Netherlands). The following retain their offices as Chairmen:

Professor P. Bastien (France), Sub-commission C (Ultrasonics)

Mr. Ludwig (Germany), Sub-commission D (Destructive Tests)

Mr. de Sterke (Netherlands), Sub-commission E (Magnetic and Penetrant Methods)

Since the 1959 Annual Assembly held at Opatija (Yugoslavia), the Commission's work has necessitated various meetings of its Sub-commissions, namely:

Sub-commission A (Radiography)—1st and 2nd March 1960 in Rotterdam (Netherlands)

Sub-commission C (Ultrasonics)—28th January 1960 in Paris

Sub-commission E (Magnetic and Penetrant Methods)—12th and 13th November 1959 and 1st April 1960 in Rotterdam (Netherlands)

Circulated or Published Documents

(1) Document IIS/IIW-46-60 (ex doc. V-87-58)—"*Handbook on Radiographic Apparatus and Techniques*"

This is an illustrated volume, of about 100 pages, for the use of engineers and technicians responsible for the radiography of welded constructions. It deals with the basic principles of radiology and provides practical information about the best working conditions.

Prepared on the initiative of Dr. Moravia (Italy) and with the co-operation of Sub-commission A, this document was drafted in English and French. The Scientific and Technical Secretariat has circulated it to each member society of the IIW.

(2) "*List of terms used in Ultrasonic Testing*" (in three languages) (ex doc. V-8-58/OE).

This printed brochure of 28 pages was published in Paris at the end of 1959 by "Publications de la Soudure Autogène" (32, Bd. de la Chapelle, Paris 18e), on behalf of the IIW.

This document was drawn up on the initiative of Professor P. Bastien and Mr. de Sterke, and is the result of the collective work of Sub-commission C.

It is a glossary in English, French and German of the most important terms in established usage in ultrasonic testing and contains both a methodical and an alphabetical classification.

To avoid ambiguity in the case of terms open to differing interpretations, the glossary contains explanatory drawings.

It is to be hoped that, with the co-operation of the national delegations concerned, the list of terms will be drawn up in other languages.

(3) Document IIS/IIW-6-58 (ex doc. V-6-57)—"*Recommended Practice for Radiographic Inspection of Fusion Welded Joints for Steel Plates up to 2 inches (50 mm) thick*"

This document, in the form of a summary, was previously circulated in 1960 to all the member societies for publication; it has been transmitted to ISO/TC 11 SC 3 (Unification of boiler codes—welded construction) and to ISO/TC 44 SC 5 (Welding—Testing and Inspection of welds).

(4) Document IIS/IIW-36-59 (ex doc. V-113-59)—"*Recommended Practice for the Radiographic Inspection Circumferential of Fusion Welded Butt Joints in Steel Pipes up to 2 inches (50 mm) Wall Thickness*"

This document, which is complementary to document IIS/IIW-6-58, was circulated by the Scientific and Technical Secretariat of the IIW for publication and was transmitted to ISO/TC 11 SC 3 and to ISO/TC 44 SC 5.

(5) Document IIS/IIW-35-59 (ex doc. V-115-59)—"*Recommended Practice for the X-ray Inspection of Fusion Welded Joints on Aluminium and its Alloys and Magnesium and its Alloys up to 2 inches (50 mm) thick*"

This study, in the form of a summary, is similar to the two preceding documents, but relates to the radiography of light alloys; it has been passed to ISO/TC 44 SC 5.

(6) Document V-139-60/OF—"*Recommended Practice concerning Image Quality Indicators for Radiography*"

In view of the importance of radiographic image quality from the point of view of the value of the radiographer's judgment of a weld, it is imperative that adequate I.Q.I's should be available and that both rules for their use and specifications for the image quality should be drawn up.

This document, also in the form of a summary meets these requirements. It was recommended for publication at the 1960 Assembly at Liège and will shortly be circulated to all the member societies of the IIW by the Scientific and Technical Secretariat (IIS/IIW-62-60 (ex doc. V-139-60)), it will later be transmitted to ISO/TC 11 SC 3 and to ISO/TC 44 SC 5.

The above-mentioned documents are the joint work of Sub-commission A and meet requests of Messrs. d'Herbemont (France), Evrard (France), Moravia (Italy) and Mullins (United Kingdom).

(7) Documents V-163-60/OF—"*The Inspection and Testing of Resinous Materials (plastics) and their welds*", *general introductory report by Professor G. Homès and J. C. Bauwens (Belgium)*

V-165-60/OE—"*Testing of welded joints in plastics*" (*Essais de joints soudés sur des matières plastiques*) *by L. Benker (Germany)*

V-164-60/OE (ex doc. V-133-50/OE)—"*Testing and inspection of welds of high density polymers*" (*Essais et contrôle des soudures de hauts polymères résineux*) *Yugoslavia.*

The business of the Colloquium organized by Commission V on Thursday, 16th June at the Liège Annual Assembly was based on these documents. The Belgian Institute of Welding was good enough to send a copy of these documents to each national delegation so that those members who were unable to take part in the Colloquium could gauge the importance of the welding of macromolecular materials, known as "plastics".

Radiographic Problems

Besides the questions covered in the documents listed above, the Commission dealt with the following problems.

The publication of a *printed atlas of characteristic radiographs*, containing an introduction, diagrams indicating defects and some annotations is in preparation. At the moment the text and the illustrations are being examined by the Scientific and Technical Secretariat of the IIW and will shortly be printed.

It was decided that within the course of the next two or three years a new edition of the *Collection of reference radiographs*, covering a wider field than the former edition, would be published. Work on this edition is now in hand.

A simple method for the *calibration of X-ray equipment* is being sought, but the investigations have not yet been completed. Discussions held on this subject have now been summarized in document VA-15-60/OE drafted by Dr. den Hartog (Netherlands).

Commission V has expressed its opinion on the *image qualities required for the radiography of welds in boilers and pressure vessels* (up to 2 inches (50 mm) thick) in document V-140-60/OF drawn up by Mr. d'Herbemont, in accordance with a request of Commission XI (Pressure vessels, boilers and pipelines). A resolution on this subject was adopted by the Commission at the 1960 Annual Assembly at Liège and noted by the Governing Council. The Commission's investigations on both the characteristics of photographic emulsions for radiography and also the radiography of light alloys are being continued, but no definite conclusions have yet been reached.

Problems Concerning Ultrasonics

The success of the list of terms used in ultrasonic testing was such that it is already planned to prepare a new edition in which some ambiguous translations will be corrected and definitions included.

Moreover, the Commission is at present engaged in the completion of a *report on material and operating techniques* used in the different countries.

Important results have been obtained from experimental research, carried out with international co-operation, into *ultrasonic response curves* in relation to different types of weld defect.

Further results are awaited and it is expected that it will be possible for a complete report to be drafted before the next Annual Assembly. This is a very important question, for the interpretation of ultrasonic indications is more difficult than that of radiographic images. Commission V is also at present dealing with the tricky problem, connected with this question, of the criteria for acceptance of welds after ultrasonic testing.

The Commission recommended at an earlier date the use of reference blocks for ultrasonic equipment. Research is being carried out at the moment to determine the influence of the nature and condition of the material which constitutes the block and to simplify the comparison of the results obtained in this connection, comparative studies are being carried out on mild steel, austenitic steel, ferritic steel, aluminium and a light alloy.

The Commission will concentrate particularly in the future, on the ultrasonic testing of welded joints in *austenitic steel*. Other questions receiving attention are the testing of *fillet welds*, *brazed joints* and *light alloys*.

Problems Concerning Destructive Tests

The atlas of test pieces used for the mechanical testing of welds, is being prepared, but is not yet ready for publication.

Commission V is collecting documents on mechanical tests suitable for welded assemblies in light alloys.

A new test piece for rapid tensile tests is the subject of a third investigation now in hand.

Problems Concerning Magnetic and Penetrant Methods

Two investigations are in progress, one on penetrant liquids and one on magnetic tests, but it is too early to draw any conclusions from them.

Problems Concerning Non-destructive Testing of Spot Welds

A joint Sub-commission consisting of members of Commission III (Resistance welding) and V of the IIW, under the chairmanship of Dr. Taylor (United Kingdom), is investigating this question.

The results of the first of a series of comparative tests between radiography and ultrasonics favoured the latter process, but it is too early to draw any conclusions.

Commission VI: TERMINOLOGY

(*Chairman—F. M. L. van Horenbeeck*—Belgium)

In accordance with its programme for the compilation of a Multilingual Collection of Terms used in Welding and Allied Processes, Commission VI has continued work on the preparation of the fourth section, dealing with Resistance Welding.

This section will be published in the following 17 languages: Czech, Danish, Dutch, English, Finnish, French, German, Italian, Norwegian, Polish, Russian, Serbo-croat, Slovak, Slovenian, Spanish, Swedish, Turkish.

As specified in the preceding Annual Report, it will comprise specific terms under the following headings:

Resistance welding-processes
Characteristics of pure resistance or flash welding
Butt welding equipment and its characteristics
Characteristics of spot welding, projection welding and seam welding
Spot welding and projection welding equipment and its characteristics
Seam welding equipment and its characteristics.

This section will include more than 350 terms, the exact connotation of some of which will be made clear by means of illustrations.

The work of drawing up these lists of terms and ensuring their exact concordance in the various languages was continued at the Annual Assembly in Liège, at which delegates and experts from 14 countries were present. This meeting had been preceded by two interim meetings, held respectively in Oslo in October 1959 and in Paris in March 1960. Commission VI will hold a further interim meeting in October 1960 in order to complete the work so that the section may be published, in 17 languages, in 1961.

Commission VI is, at the same time, preparing the publication of supplements to the Gas Welding, Arc Welding and General Terms Sections; the supplements which will contain the terms in Czech, Polish, Russian, Slovak and Turkish, will also appear next year. The conditions in which publication will take place were the subject of a resolution adopted by the Governing Council.

Finally, in a second resolution also adopted by the Governing Council, Commission VI asked that every effort be made by the member societies to advertise these supplements as widely as possible among their members.

Commission VII: STANDARDIZATION

(*Chairman—A. Leroy*—France)

Commission VII, which met at the Opatija Annual Assembly in 1959, held a further session at Liège on 13th, 14th and 15th June 1960.

Representatives of the following countries took part in its work: Belgium, France, Germany, Netherlands, Sweden, United Kingdom, United States, USSR, Yugoslavia.

In addition, Mr. Gougelot, delegate of the French Standards Association (AFNOR), which is responsible for the General Secretariat of the Committee ISO/TC 44 (Welding), was present at the meetings of the Commission.

The principal purpose of Commission VII is, of course, to ensure that the closest and most fruitful links are maintained between the IIW and the ISO. With this aim in mind, the Commission examines the results of the work of the IIW technical Commissions which are, or might be, useful to the ISO. The Commission is equally informed of the problems raised or discussed within ISO Committees, so that any points affecting the various technical Commissions of the IIW can be transmitted to them either for information, or in order to obtain contributions to the work on certain questions.

The principal documents on which Commission VII's work was based were the following:

Information of the Scientific and Technical Secretariat for the coordination of the work of the Commissions (document SST–247–60)
Report of the meeting of Chairmen of Commissions held on 30th January, 1960, in Paris (document SST–263–60)
Memorandum on the symbolization of filler metals used in surfacing (document SST–222–59—VII–149–59)
Draft code of symbols for filler metals used in gas surfacing (document IIS/IIW–33–59—I–108–59—VII–164–60)
Draft code of symbols for filler metals used in braze welding by gas flame (document IIS/IIW–34–59—I–110–59—VII–165–60)
Code of symbols for filler metals used in hard-surfacing. Electrodes (document II–127–60—VII–166–60)
Testing method for determining the mechanical properties of

the weld metal deposited by deep penetration electrodes (document II–63–59—VII–168–60)
Information on the meetings of the Committee of Experts No. 1 of Committee 26 of the IEC (International Electrotechnical Commission) which took place in London in 1958 and in Brussels in 1959 (documents VII–155–60 and VII–156–60).

1. WORK OF THE IIW LIKELY TO ASSIST ISO/TC 44 "WELDING"

1.1 Work affecting Sub-committee 3 (Filler metals and electrodes)

1.1.1 *Symbolization of filler products*

Commission VII has noted that the arrangements laid down in documents VII–164–60 and VII–165–60, which were examined by Commission I (Gas Welding and Allied Processes), and which concern respectively the symbolization of filler metals used in gas surfacing and that of filler metals used in brazing by gas flame, are in accordance with the principles laid down in document VII–149–59.

It will be remembered that this latter document contains general rules concerning the symbolization of filler products used in surfacing and was, last year, the subject of a detailed examination by Commission VII.

On the other hand, examination of document VII–166–60 relating to hard-surfacing electrodes, previously studied by Commission II (Arc Welding), showed that the arrangements proposed by this Commission differed on several points from the methods envisaged for the symbolization in document VII–149–59, mentioned above.

In the light of this, Commission VII adopted a resolution recommending in particular that:

Document II–127–60 be transmitted to ISO/TC 44/SC 3 for consideration at its next meeting.*
Account being taken of the differences featured in documents I–108–59 and II–127–60 ISO/TC 44/SC 3 should establish the principles on which the symbolization of filler products used in hard surfacing or surfacing in general should be based, it being understood that the IIW is prepared to help Sub-committee 3 with such further collaboration as may be necessary.
The IIW should be represented at the next meeting of ISO/TC 44/SC 3 by two observers, namely: the Chairman or a member of Commission I on the one hand and of Commission II on the other.

The Governing Council approved this resolution and, in the light of the resolutions relating to the same problems submitted by Commissions I and II, asked the Scientific and Technical Secretary to send document II–127–60 to ISO/TC 44/SC 3, together with, for information, document SST–222–59 and a letter stating in particular:

(*a*) That the IIW is ready to assist the ISO both in the work on a general method of symbolizing filler products and, equally, in the more specialized case of filler metals for surfacing, these questions forming part of the working programme of the Institute
(*b*) That the IIW would appoint two observers to attend the next meetings of ISO/TC 44/SC 3, as stated in the last paragraph of resolution 1 of Commission VII.

1.1.2 *Mechanical properties of the weld metal deposited by deep penetration electrodes*

Document VII–168–60 has already been transmitted to the Secretariat of Sub-committee 3 as it deals with the revision of matters of detail in an early document, examined, when it was first drawn up, by Commission VII.

1.1.3 *Filler metals used in gas welding—Tests to determine the compatibility of filler metals and base metals in the welding of steels—document I–79–58—IIS/IIW–29–58*

Following its examination last year by Commission VII and its transmission to the Chairmen of Commissions II and XII (Special Arc Welding Processes), this document was forwarded to the Secretariat of the ISO/TC 44/SC 3.

1.2 Work affecting Sub-committee 4 (Arc welding equipment)

The Scientific and Technical Secretariat sent the following document to the above-named Sub-committee: IIS/IIW–28–59 (Characteristics of current sources for special arc welding and cutting processes) which, having been drawn up by Commission XII (Document XII–40–58), was examined last year by Commission VII.

1.3 Work affecting Sub-committee 5 (Testing and control of welds)

Sub-committee 5 is to meet in Genoa in December 1960. Its work will be helped by a contribution, in the form of the following documents, from the IIW:

IIS/IIW–23–59: Results of investigations undertaken by Commission V of the IIW on the use of reference blocks for checking apparatus for ultrasonic inspection.
IIS/IIW–35–59: Recommended practice for the X-ray inspection of fusion welded joints on aluminium and its alloys up to 2 inches thick.
IIS/IIW–26–59: Recommended rules for the qualification of welders—Manual metal-arc welding and gas welding of steel.
IIS/IIW–36–59: Recommended practice for the radiographic inspection of circumferential fusion welded butt joints in steel pipes up to 2 inches wall thickness.

In this connection, Commission VII passed a resolution, subsequently adopted by the Governing Council, recommending that the IIW should be represented by the following observers at the next meeting of Sub-committee 5: one or two members of Commission V (Testing, Measurement and Control of Welds), in particular for the consideration of questions concerning ultrasonic and radiographic inspection; one member of Commission XIV (Welding Instruction), in particular for the consideration of the rules for the qualification of welders.

2. CONTRIBUTIONS FROM THE IIW TO ISO/TC 11 "UNIFICATION OF BOILER CODES"

Sub-committees SC 1 "Boiler equipment", SC 2 "Resistance of parts under pressure", SC 3 "Welded Construction" of the ISO/TC 11 met in June 1960 in Düsseldorf.

The IIW appointed some observers, the meeting of Sub-committee 3 having taken place immediately before the IIW Assembly.

These Sub-committees had the following IIW documents at their disposal:

IIS/IIW–39–59: Recommended welded connections for pressure vessels.
IIS/IIW–6–58: Recommended practice for radiographic inspection of fusion welded joints for steel plates up to 2 inches thick.
IIS/IIW–36–59: Recommended practice for the radiographic inspection of circumferential fusion welded butt joints in steel pipes up to 2 inches wall thickness.

* In the meantime, the meetings of ISO/TC 44/SC 3 have been fixed for 16th, 17th, and 18th January 1961.

Commission VII considered a provisional report drawn up by the IIW observer on SC 3 (Doc. VII–178–60) in which it was stated that this Sub-committee had considered document IIS/IIW–30–59 and had made a certain number of amendments to it, with a view to forming an appendix to the code drafted by ISO/TC 11. Furthermore, with regard to the quality of welds from the point of view of the definition of the "acceptable defects revealed by radiographic examination", ISO/TC 11/SC3 is waiting for the results of the investigations made by the Working Group "Non-Destructive Inspection" of Commission XI (Pressure vessels, boilers and pipelines) of the IIW.

3. WORK OF ISO/TC 44 AFFECTING VARIOUS IIW COMMISSIONS

Since the IIW meeting in Opatija, there have been no further meetings of the various Sub-committees of ISO/TC 44.

Nevertheless, apart from what is said above with regard to Sub-committees 3, 4 and 5, it was mentioned in Commission VII that Sub-committee 3 is to consider at its next meetings, the work of Sub-committee 1 "Definition of Weld-Position" with a view to amending ISO draft recommendation No. 178 concerning the Code for the international symbolization of covered electrodes for welding mild steels and low alloy high-tensile steels.

4. LIAISON WITH ISO/TC 37 "TERMINOLOGY"

Following a resolution passed by Commission VI (Terminology) last year at the Opatija Assembly, the IIW recommended to ISO/TC 37 the use of all the draft symbols for the designation of languages, presented by Mr. Holmstrom of UNESCO.

The Chairman of Commission VI has been informed through the Scientific and Technical Secretary, about ISO/TC 37 working documents relating to the preparation of multilingual vocabularies. Although the IIW observer appointed to follow the work of ISO/TC 37 in Berlin in May 1960 was prevented from attending these meetings, it is understood that the results of the work will be made known to the IIW.

5. WORK OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)—RESEARCH COMMITTEE

No. 26—Electric welding—Experts' Committee No. 1—Safety regulations for electric welding equipment

The Experts' Committee met for the second time on 8th and 9th December 1959 in Brussels; the IIW had appointed an observer to attend these meetings. The main work of this Committee dealt with:

The earthing of welding circuits: three types of connection shown in diagrams will be recommended, their selection depending on the relevant conditions.
The di-electric rigidity of arc welding apparatus.
General rules governing the extension of welding cables.

In addition, other work is being carried out concerning electrode-holders for arc welding and various rules relating to the safety of resistance welding machines. It has been noted that Commissions II, III (Resistance welding) and XII of the IIW are being kept informed of the work of Committee 26 of the IEC and, also, that Commission II will be able to reply to the questions asked last year by Committee 26 concerning:

(1) The maximum current densities admissible in welding cables insulated with polychloroprene in relation to the diameters of the cables,
(2) The maximum open circuit voltages used in arc welding with covered electrodes.

6. DIRECTION TAKEN BY THE WORK OF VARIOUS IIW COMMISSIONS CONCERNING CERTAIN STANDARDIZATION PROBLEMS

(1) In view of the fact that arising out of the work of Commission II and the decisions taken in Opatija, a suggestion was made to ISO/TC 44 to use V-notch Charpy test specimens to determine impact values in the symbolization of electrodes, which was the subject of the ISO draft recommendation No. 178, Commission VII passed a resolution recommending that Commission I should also study a similar proposal for the determination of impact values in the symbolization of filler metals, the subject of ISO draft recommendation plan ISO No. 226. This resolution was adopted by the Governing Council.

(2) Arising out of the wish expressed last year by ISO/TC 44/SC 1 (Definition of weld-positions), it was confirmed that Commission III had been invited to make proposals concerning the definition of weld-positions for the manual arc welding with covered electrodes of pipelines.

(3) Commission VII has noted the fact that, with regard to the symbolization of filler metals for surfacing, Commission XII has decided to study, first, that of filler metals which can be used with the TIG process.

7. PREPARATION OF LISTS OF NATIONAL STANDARDS RELATING TO WELDING

Following the decisions taken in 1959, 12 lists of standards were sent to the member societies of the IIW. New lists have been received from the following countries: Australia, Austria, Finland, Norway, Roumania, Spain, Yugoslavia, while the original German and USSR lists have been brought up to date. One copy of documents will be sent to the member societies of the IIW.

8. OTHER BUSINESS

It was reported that the Scientific and Technical Secretary has had the opportunity of pointing out to Mr. Saint-Léger, Secretary-General of ISO, the desirability of revealing more widely information on the development of work carried out by the Technical Committees of ISO and that arrangements may be made in this connection by ISO when the problem has been studied.

9. PROGRAMME OF FUTURE WORK

In the interval between the IIW Annual Assemblies, Commission VII will be informed of work carried out in the various IIW Commissions during the Liège Assembly which is of interest from the point of view of general standardization. Moreover, the work of collecting lists of national standards will be continued. The business at the 1961 New York meeting will, as is customary, be the examination of questions discussed within the IIW on the one hand and by the Technical Committees of ISO on the other which involve liaison between these organizations.

International WELDING

Characteristics of Current Sources for Special Arc Welding and Cutting Processes

PREFACE

*by J. C. Needham, B.Sc.**

COMMISSION XII of the International Institute of Welding is concerned with the Special Arc Welding Processes (that is, all those processes apart from metal-arc welding) and the Working Group "f" deals with the problems of power sources for these several processes. This report (IIS/IIW–28–59) represents the published findings of the Working Group, as given at the 1959 Annual Assembly of the IIW at Opatija, and includes some proposals for the definition or rating of the output characteristics of welding power sources. It was hoped that this year a concensus of opinion could have been arrived at for the desired or optimum characteristics to be used for particular welding and cutting processes; but, apart from any disagreement and differences in practice in various countries, the issues were complicated by the introduction of yet further types and usage of power source, such as in the short-circuit transfer technique applied to the CO_2 welding of steel at low currents.

However, until this fuller report of the Working Group is available, the present interim report provides a worth-while basis for the description of power plant and for some co-ordination in specification. The welding processes listed are classified largely by obvious external features such as the overall technique, type of electrode and shielding gas and so forth, but the power source characteristics required cut across these boundaries and are governed by other considerations such as constant electrode feed (self-adjusting arc), and magnitude of arc voltage. However, for simplicity the specification for power plant for manual metal-arc welding is followed as far as possible and note taken of the main deviations, *cf.* the conventional load voltage section (2.1).

This is justified since the *electrical* characteristics of a given plant stand substantially irrespective of the welding process for which it is used. Thus, though a machine may normally be rated for example as 250 amp output at 30V load for manual metal-arc use, according to design details the manufacturer could provide alternative specifications which the machine would be equally capable of meeting without overload or other difficulties, such as 350 amp at 20 V and 150 amp at 45 V. Similarly, a plant capable of high short-duration currents as in stud welding, could also serve at much reduced current on a continuous duty cycle.

In the corresponding British Standard BS.638:1954, the load voltages chosen are not quite the same but the difference is more a question of arbitrary choice rather than technical significance. Again the currents quoted are in round hundreds in *hand-welding* current (and this is multiplied by a test load factor, about 0·7, for the continuous test current) whereas in the IIW report the currents tend to be in round figures as a *continuous* rating, *i.e.*, for 100% duty cycle.

The latter part of this report deals with the relation between output voltage and current—the output characteristic which is often loosely referred to as 'steep', 'flat', or 'rising'. Here the main criterion taken

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Report IIS/IIW–28–59 of Commission XII "Special arc welding processes", Working Group "f" "Power sources for all processes" of the International Institute of Welding. 600

is the constant potential type output, which is defined as having a change *either* falling or rising of less than 2 V per 100 amp, and any characteristic outside this range is drooping or rising. In the drooping characteristic group, distinction is made between an output termed "constant current", which falls steeply through the normal working point so that the short-circuit current is similar to the welding current, and the "constant power" type where the output slope is somewhat less steep and is often approximately linear from open-circuit voltage to short-circuit current.

The significance of the slope of the power source output characteristic in relation to the welding process is not discussed in this report and is only briefly given here as a guide. For any arrangement with a fixed arc length as in tungsten-argonarc and carbon-arc welding, where the electrodes are non-consumable, the arc current must be externally controlled since the arc does not behave as a constant resistance. Hence a "drooping" power source is used which, by its setting, largely controls the current, and the greater the downward slope through the particular operating point the more nearly is the current constant and independent of arc voltage or arc length changes.

Also, in all consumable electrode processes (submerged-arc, gas-shielded metal-arc, etc.), where the electrode feed is controlled by the arc voltage, the current must be externally controlled and again a drooping characteristic is used. This is so that the current may be predetermined by the power source and the electrode feed made to match the burn-off rate, for otherwise if the current were allowed to vary freely there would be no stable operating point. The feed is the dependent variable, governed by the arc voltage, such that an increase in arc voltage (or arc length by implication) increases the feed rate until an equilibrium is reached.

The converse applies to self-adjusting arc operation. Here the electrode feed is the predetermined factor and the current must be made to give the required burn-off rate, that is, the current is now the dependent variable and it can be governed by the arc by using a power source with a near flat output characteristic. Here, considering a very slightly falling output (*cf.* Fig. 3), a small drop in arc voltage results in a comparatively large increase in current. Thus if the burn-off rate (current) were less than the pre-set feed rate, the reduction in arc length (arc voltage) would cause an increase in the current until equilibrium was reached. (This simple argument cannot be applied to a true constant potential or a rising characteristic power source. In these cases it can be taken that a decrease in arc length corresponds to an effective decrease in resistance of the arc and hence in an increase in current from the power source until the burn-off matches the feed rate.)

It is to be noted that with the constant electrode feed system, a strictly constant current source (*cf.* Fig. 1) cannot be used as there is no automatic correction of current to give the required burn-off. In practice a power source with a moderately drooping output characteristic (constant power type, Fig. 2) can be used since there is some control of current by the arc voltage. However, this requires the power source to be set so that the current is fairly carefully matched to the feed rate, as the degree of self adjustment of the system is low compared with using a power source with a near flat output characteristic (constant potential type).

1. Process Classification

The different special arc welding and cutting processes may be classified as follows:

A.1—Automatic and semi-automatic open arc welding

A.2—Automatic and semi-automatic submerged-arc welding.

A.3—Automatic and semi-automatic gas-shielded arc welding using non-consumable electrodes.

A.4—Automatic and semi-automatic gas-shielded metal-arc welding.

A.4–1—Inert-gas arc welding.

A.4–1.1—Argon-shielded arc welding.

A.4–1.2—Helium-shielded arc welding.

A.4–2—CO_2 shielded arc welding.

A.5—Other processes.

A.5–1—Stud welding

A.5–2—Inert-gas arc cutting.

A.5–3—Automatic slag-welding.

2. Power Source Specifications

This paper deals with the current sources for these different processes. These current sources, whether d.c. or a.c., will be defined* not only by their rated welding current at the conventional voltage under load for several conventional welding duties, but also by their load characteristic: $V_L = f(I)$.

2.1 Conventional voltage under load

The study of the arc voltage/current curves shows that for the A.1, A.2, A.4–1.2, A.4–2 and A.5–1 processes, the voltage values are close to those obtained in manual arc welding with covered electrodes.

For the A.4–1.1 process with argon shielding, voltages are a little lower.

For the A.3 process voltages are much lower but for the A.5–2 process they are, on the other hand, much higher. For the A.5–3 process, full technical information is not yet available.

The law relating the voltage variation in the welding equipment to the current, adopted for equipment for manual arc welding with covered electrodes may then be used for the A.1, A.2, A.5–1 processes and, by extension, for all the A.4 processes. This law is defined by the linear relationship:

$$V = (20 + 0{\cdot}04I) \text{ volts}$$

which gives: (I being expressed in amp)

20 V for 0 amp
44 V for 600 amp

For current over 600 amp, the voltage remains constant at 44 V.

* For the definitions of the conventional voltage under load, conventional welding duty, rated welding current, *cf.* Draft ISO proposals for the rating of manual metal-arc welding equipment (ref. ISO/TC.44 (Sec.III) 163 E and F considered by ISO/TC.44 "Welding" in December 1957.

For the A.3, A.5–2 and A.5–3 processes, other relationships for voltages as a function of current will be discussed in a further paper.

2.2 Conventional welding duty

For the A.1, A.2, A.3, A.4 processes with semi-automatic welding, it is proposed to adopt a duty cycle of 0·8 with 5-minute cycle, identical to that adopted in manual welding with covered electrodes, and a duty cycle of 1 for these processes with automatic welding. The 5-minute duration for the duty cycle of 0·8 means 4 minutes on and 1 minute off.

For the A.5–1 process (stud welding), because of the many short-circuits, a duty cycle of 0·1 with a 15-second cycle (that is, 1·5 seconds on and 13·5 seconds off) is recommended.

2.3 Rated welding current

A few types of equipment may have to be used either with manual electrodes, or with one of the A.1, A.2, A.3, A.4 processes, so the rated welding current will be given for the different duty cycles (0·6–0·8–1) and even 0·1 is used for the A.5–1 process. (*See* preceding paragraph.)

2.4 Grading of equipment

Equipment will be graded according to the relation:

$$V = (20+0{\cdot}04I)$$

previously mentioned in paragraph 2.1, this grading being used for the A.1, A.2, A.4 and A.5–1 processes. A chart will give the corresponding welding current in relation to this grading when the equipment is used for the A.3 process, in which welding voltages are much lower.

2.5 Characteristics under load of welding equipment

Welding equipment is defined by a series of characteristics $V_L=f(I)$, each of which corresponds to a setting. Thus, each type of equipment may be classified in one of the following three main categories:

welding equipment with drooping characteristics,
welding equipment with constant potential characteristics,
welding equipment with rising potential characteristics.

(*a*) *Welding equipment with drooping characteristics*

Such equipment is used in manual welding.

Its characteristics are called "at constant current" when the short-circuit current is hardly greater than the welding current (Fig. 1).

They are called "at constant power" when the characteristic curve makes a small angle with the current axis (Fig. 2).

(*b*) *Welding equipment with constant potential characteristics*

These characteristics are represented by a series of approximately horizontal curves, each of these being determined by a no-load voltage of the equipment which can generally be regulated.

The maximum slope of each characteristic curve is such that, within the scope of the equipment (from $0{\cdot}2\ I_m$ to I_m the variation of voltage must not be over ± 2 V between 2 points with a difference in current of 100 amp.

(I_m is the rated current with a 0·60 duty cycle.)

Example

Equipment with a rated current of:

500 amp at a duty cycle of 1
560 amp at a duty cycle of 0·8
640 amp at a duty cycle of 0·6

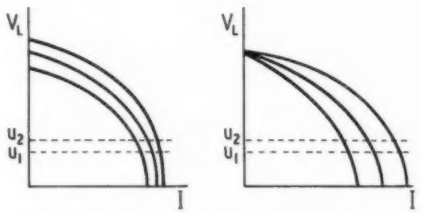


Fig. 1

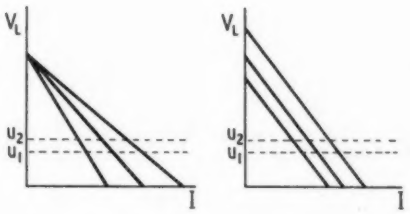


Fig. 2

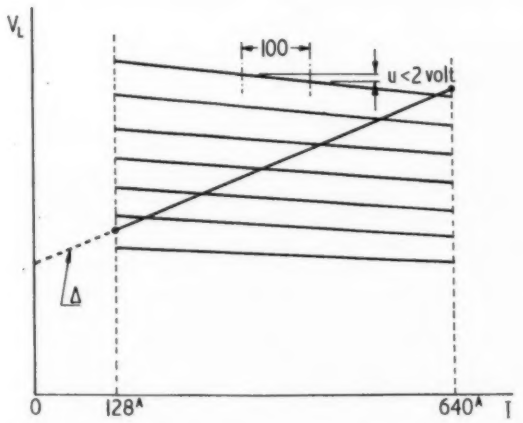


Fig. 3

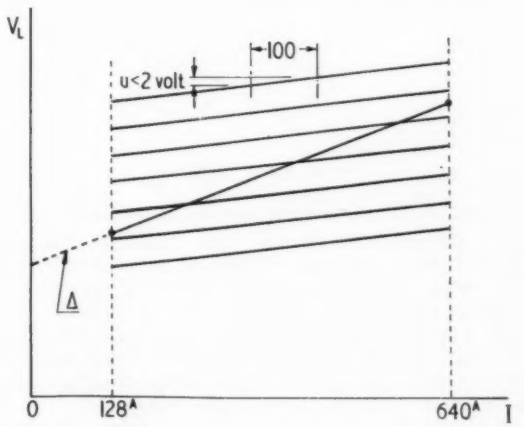


Fig. 4

Δ = conventional voltage line (V = 20+0·04I)

Limits of temperature rise

	Class of Insulation	*A*		*E*		*B*		*F**		*H**	
		T	R	T	R	T	R	T	R	T	R
1	(*a*) a.c. windings (*b*) Field-windings of a.c. and d.c. excitation other than those in Item 2 (*c*) Windings of armatures having commutators	50	60	60	70	65	80	85	100	105	125
2	Low resistance field windings of one or more layers and compensating windings	60	60	70	70	80	80	100	100	125	125
3	Iron core and other parts in contact with windings	60		75		80		95		110	
4	Commutators and slip rings, open or enclosed	60		70		80		80		80	

T = by thermometer; R = by resistance

* The numerical values quoted for classes F and H should be considered as tentative only and may be the subject of revision when more practical experience is available.

under a conventional potential defined by the relation:

$$V_L = (20+0{\cdot}04I)$$

will have characteristics such that between the two current limits of I_m=640 amp and 0·2 I_m=640×0·2=128 amp; the potential variation will be less than 2 V between the two values I and I+100. (I=any value of current.) (Figs. 3 and 4.)

(*c*) *Welding equipment with rising potential characteristics*

These characteristics are represented by a series of slightly rising curves, each of them being determined by a no-load voltage of the equipment which can generally be regulated.

The slope of each characteristic is such that within the scope of the equipment (from 0·2 I_m to I_m) the variation of voltage must be greater than 2 V between two points with a difference in current of 100 amp. (I_m=rated current with a 0·60 duty cycle.)

2.6 Temperature rise of welding equipment

The upper limits of temperature rise of welding equipment for the special processes are the same as those adopted for equipment for manual welding with covered electrodes; these limits were proposed and discussed by the Committee ISO/TC.44 in December 1957; they are given in the appended table.

Temperature tests are to be carried out until the rate of temperature rise does not exceed 2°C./hr on any component part of the equipment.

Temperature measurements are to be made immediately after the machine has stopped in the middle of the last on-load period, where the duty cycle is less than 1.

Pressure Vessel Brittle Fracture and Information Required to Design against It

By A. A. Wells (United Kingdom)

Incidence of Failures

Pertinent cases from published work and other sources

In comparison with steel ships, building structures and heavy welded components in general engineering, pressure vessels are often less complex in conception, smaller, and may be fabricated under better conditions. Careful search suggests that there are also fewer published references to brittle fractures in pressure vessels than in some other types of structure, even if relative numbers are considered.

Failures in five large spherical or cylindrical welded storage vessels and in a number of oil storage tanks are described by Shank[1] in a comprehensive report embracing experience in several countries. These vessels were not stress relieved. Many cases of brittle fracture in gas storage bottles in France are described by de Leiris, Couture and Crussard.[2] Both mild and high strength steels were involved and two-thirds of the fractures were preceded by recognisable stress corrosion cracking. These vessels were mainly of the one-piece forged type. Several brittle fractures in the U.S.A. of forged or fusion welded steel vessels are

Report IIS/IIW-54-60 of Commission XI "Pressure vessels, boilers and pipelines" of the International Institute of Welding.

described by Puzak, Babecki and Pellini[3] and also by Galletly.[4]

In addition to the existence of notch brittle conditions in the materials of construction, together with pre-existing notch effects, some of the features associated with one or more of the cases mentioned in the two latter reports are gross yield during hydrostatic test, welding after stress relieving and stress relieving at too low a temperature. Reports from classification societies and insurance companies in the United Kingdom appear to include no service failures by brittle fracture in mild or low alloy steel vessels which previously had been furnace stress relieved. Brittle cracks appearing during fabrication by welding of thick drums are described by Harris.[5] It is suspected that more such fabrication fractures arise than are reported.

Transition Temperatures

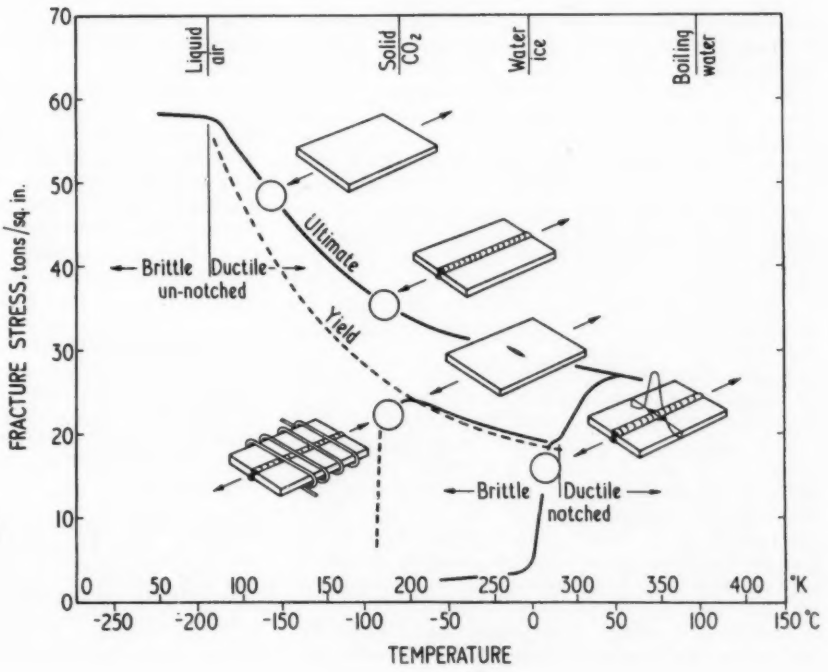
It is recognised that the initiation and propagation of brittle fractures in steels such as are used for pressure vessels are dependent upon temperatures. A vast literature is addressed to this single feature. Parker,[6] Shank,[7] and Tipper[8] have each contributed reviews. Evidence suggests that no precise temperature may be assessed for a steel to denote positive transition from the ductile to the brittle fracture mode, except when at least notch severity and loading rate conditions are defined in advance. Nevertheless, for practical purposes, tests for brittle fracture transition temperature assessment may be chosen to give a usefully close indication. Sub-commission A "Comparison of brittle fracture tests" of Commission IX "The behaviour of metals subjected to welding" have given attention to this matter.[9]

Even in hydrostatic overpressure testing of vessels it is not usual for gross plastic deformation to occur, except in special circumstances.* The mode of eventual fracture, whether shear or cleavage, would therefore be unimportant if the deformation to fracture were large in both cases, as in the simple notched tensile test at temperatures near to the fracture appearance transition temperature. The pressure vessel designer is accordingly interested in the conditions which permit a change from high to low ductility, or even to fracture at low applied stresses, and this is intensified under conditions, such as large section thickness, where sufficiently low fracture appearance transition temperatures are difficult to achieve in the construction materials. The philosophy is not novel; steel rails are judged safe under their conditions of use even when known to be notch brittle at atmospheric temperatures, because their deformation to fracture during test is much larger than deformations during service.

It has been found that misleading results are sometimes, if not invariably, obtained if the detailed ductility behaviour of small mechanical test specimens is extrapolated to predict that of larger structures, because of intervention of so called size effects, both metallurgical and geometrical. A smaller possibility of error exists when test results are taken from specimens approaching in scale and construction those of the structures or pressure vessels themselves, and a growing body of information exists in this field, which is typified in Fig.1.

If notch effects are absent, an increase of size does not produce of itself significant strength reduction

* The pre-stressing of gas transmission pipes would be an example of this.



1—*Typical wide plate strengths for mild steel (diagrammatic)*

Table I

Suggested influence of precautions on pressure vessel brittle fracture

Precautions				*Type of fracture*		
Notch ductile material	*Well rounded design detail*	*Absence of flaws*	*Thermal stress relief*	*Ductile*	*Brittle After gross yield*	*Brittle Low stress*
Yes	Irrespective	→	→	X		
No	Yes	Yes	Yes	X		
No	Yes	Yes	No	X		
No	No	Yes	Yes		X	
No	Yes	No	Yes		X	
No	No	Yes	No		X	
No	No	No	Yes		X	
No	Yes	No	No			X
No	No	No	No			X

or a change of fracture mode, as was shown in tests of large butt welded specimens by Wilson and Hao,[10] and of large scale hatch corner specimens where design notches were minimised, by De Garmo.[11]

Moreover in mild steels of pressure vessel quality, brittle fracture cannot apparently be induced without a pre-existing notch effect until temperatures are very low indeed.[12,8] In the presence of the notch effect, yield point or higher stress failures are experienced down to intermediately low temperatures;[13,14,15,16] for instance, Kihara and Masubuchi[17] show the possibility of maintaining the high fracture strength down to −70°C., even with arrested cracks as initial notch effects in a steel with a fracture appearance transition temperature of 40°C. Low stress fractures at temperatures higher than the foregoing, but still below the fracture appearance transition, appear to require the notch effect to have been associated with some previous thermal effect or deformation or both, such as may be obtained by placing a notch in an edge prepared for butt welding,[17,18,19,20] or by precompressing a notched specimen.[21]

This outline of the ductility behaviour of mild steels, although substantially correct and widely applicable, may nevertheless require care in interpretation, as for instance with thick plates whose transition temperatures may be raised disproportionately by overheating for fabrication operations. It may also require revision if higher strength alloy steels are considered; in some cases,[22,23] with such steels, the requirement for general yielding to precede fracture initiation in specimens devoid of previous notch deformation is not so pronounced or spread over such a wide temperature band as for mild steel.

Brittle cracks in large plates do not require high applied stresses for the maintenance of propagation, as is obvious from a study of casualties. Actual low stress values which are required have been measured for many steels by Robertson.[23] Parallel studies by Felbeck and Orowan,[24] Irwin[25] and others show that the stress to maintain propagation also depends on the current crack length; it is high for short cracks, and *vice versa*. Moreover, there is strong evidence that propagation may be enhanced by the presence of residual stresses, from welding for instance.[20]

Tensile tests which have been made on notched and welded wide plates following both mechanical and thermal stress relieving treatments show that a restoration of yield point strength may be achieved.[18,20,26] In the case of thermal stress relieving at 650°C. with mild steel, the embrittlement at the root of the notch arising from the welding operation is also obliterated (Fig. 1), because the plastic extension capacity of the whole plate is restored to that which would arise in the notched, unwelded condition, that is ½–1% at a temperature 70°C. below the fracture appearance transition temperature.[18,26]

Consideration of Present Practice

The information arising from experimental studies, and particularly from the larger scale tests, supports much of what is at present considered good practice in pressure vessel construction. Accumulated data suggest a situation as summarised in Table I. Thus, brittle fracture does not appear to be a problem:

1. when service is confined to temperatures above the transition temperature of the material (almost irrespective of associated conditions)
2. in vessels with well rounded details,* if fabrication flaws are absent (almost irrespective of operating temperatures).

Brittle fracture will almost certainly not occur in the operating range of loading (irrespective of operating temperature, to a limit 100°C. below the transition temperature):

1. in vessels without well rounded details, but with an absence of flaws
2. with an average rounding of details, but in the presence of fabrication flows (such as might occasionally be missed in non-destructive examination), provided that the residual stresses and local embrittlement arising during fabrication have been removed by a furnace stress-relieving operation.

However, brittle fracture will, under these conditions, be a hazard during fabrication, or if welding is attempted after stress relieving, but one subject to statistical considerations and an acceptable risk in some circumstances. The statistical consideration is associated with scatter in measured behaviour, contributed appreciably by differences in flaw severity and to a smaller extent by material non-uniformity. Although information exists for mild steel with artificial crack-line flaws of the order of 0·1–1·0 in.² cross-section, much more remains to be learned about flaw effects, in particular as to variations in severity with flaws of comparable dimensions.

Suggested Design and Fabrication Procedure

In order to take account of the possibility of brittle fracture in a projected pressure vessel, the designer accordingly needs to consider, or specify in relation to the following (however, available information may be inadequate):

1. *Duty*—This could be categorised in degrees from (for instance) buried water tanks, to containers for nuclear reactors, to assess the consequences of failure. An acceptance of widely different chances of failure would be implicit, even if not assessed

* In the sense of avoiding substantial concentrations of stress.

quantitatively. For reference, the failure rate by brittle fracture for welded oil storage tanks and ships where, until recently, precautions on steel, welding and non-destructive testing were not extensively applied, has been between 0·1 and 1 major fractures per million tons of steel per year.

2. *Material*—The appropriate property to be assessed is transition temperature in relation to service or fabrication temperature. Agreement on the test criterion to be applied for assessment of transition temperature is not unanimous on an international level. The test with widest application is the Charpy V notch, which gives an energy absorption, versus temperature record. There is wide agreement that the adoption of a universal arbitrary energy level with this test to assess transition temperature is unsound. Equally, the adoption of fracture appearance may unwarrantably favour certain types of steel. Of the many other available tests, none is at present without disadvantages. For the time being, choice of test and criterion can be a matter between client, supplier and insurer. In spite of ambiguities and the shortcoming of tests when it is required to select one for universal application, there is little difficulty in individual cases, when information relating to service experience or to the results of more extensive testing with steels of similar origin is available.

   Nevertheless, the acquisition of information relating to the alloy steels in increasing use for pressure vessels is a firm requirement; more information may also be needed where transition temperatures move upwards during service, as for instance from strain ageing induced by cycles of local plastic strain from hot spots, and in the case of irradiation.

3. *Design*—There is little evidence that the stress concentrations in pressure vessels designed according to present day standards represent notch effects sufficient of themselves to initiate brittle fractures under service conditions. On the other hand, many cases exist where poor design has engendered inaccessibility and restraint sufficient for the introduction of weld flaws at these same points of stress concentration, such that brittle fractures have ensued. Assessment of fracture risk calls for examination of accessibility for welding and freedom from undue restraint, while at the design stage.

4. *Welding*—Flaws or discontinuities in welded joints are potent sources of brittle fractures when other necessary conditions have already been satisfied. In particular, the cracking tendencies (heat-affected zone, or weld metal) associated with any proposed welding processes require assessment, in relation to the conditions in which these processes are likely to be used (material, thickness, degree of pre-heating, etc.). Equally, it would be inappropriate to deposit weld metal of notch ductility greatly inferior to that of the plate material. Information to permit sound judgments in the case of established welding processes is embodied in the codes of several countries. The establishment of comparable knowledge for newer processes (of which electro-slag welding is but one) could be facilitated by the testing of welded wide plates and pilot vessels, as well as by the more familiar small scale acceptance tests.

5. *Non-destructive testing*—It is well known that quality standards in welding may be raised by use of methods which expose flaws as they are created. Crack-like flaws of the type sometimes found may propagate as brittle fractures under given conditions. In other cases, complete freedom from flaws may remove the brittle fracture hazard, even when other conditions for fracture are satisfied. The thicknesses which are now being fabricated into pressure vessels are becoming difficult to examine satisfactorily with existing non-destructive testing processes, and further development may be required.

6. *Post heat treatment*—The efficacy of a furnace treatment on carbon steels for the relief of residual stress and embrittlement in relation to prevention of subsequent brittle fracture has been demonstrated. Certain localised heat treatments, as well as mechanical stress relief, may also be efficacious. Post-heat treatment may be considered either as supplementary or alternative to the precautions given under headings 2, 3, 4 and 5, depending upon duty, and the fracture probability which is desired.

7. *Overpressure testing*—This cannot be disregarded as a cause of rupture in itself. Evidence from casualties suggests that gross yield during hydrostatic test may induce immediate fracture, where testing at pressures closer to working levels would have shown complete safety. It is questionable in certain cases whether the radical improvement of material which would be required to secure complete insensitivity to gross yield in the hydrostatic test would be warranted, when the arbitrary nature of overpressure factors is considered. A case may be made both for re-examination of these factors, and for studies to examine the plasticity limits* for pressure vessel components designed according to current requirements. Revised factors might well be based upon results of the latter study.

Summary

It is suggested that a body of knowledge exists that is sufficient to permit design against brittle fracture in pressure vessels welded with established processes in materials which are primarily low carbon steels, having manganese as the only metallic alloying element present in a significant quantity. Although some doubt still exists as to the precise definition of the transition temperature of a material, and the most suitable method of measurement, this temperature may be assessed sufficiently well for practical purposes. Function below the transition temperature of the material can be guaranteed as safe in many cases, providing in these cases the service temperature is always above the transition temperature of the construction in an assumed flawed condition, as measured on the basis of static strength and deformation to fracture. The practices which would lead to safe

* Reference may be made to the document to be prepared on design against excessive plastic deformation (doc. XI–35–59).

behaviour judged in this way are especially applicable to deal with situations where the transition temperature of the material and the service (or fabrication) temperature are ambiguously close or overlapping.

Further study is required to extend the variety of vessels which may be safely designed. In particular, alloy steel vessels and new, potentially valuable welding processes require further assessment, particularly in test situations appertaining to pressure vessel service.

Work at present in progress in the United Kingdom is likely to provide information in the near future on the following subjects:

(*a*) Correlation between small scale transition temperature tests and welded wide plate tests in a variety of low carbon steels
(*b*) Crack propagation behaviour in wide plates
(*c*) The influence of flaw types on fracture strength in welded wide plates
(*d*) The effect of large plate thickness on the fracture strength in welded wide plates.

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1961 Annual Assembly of the International Institute of Welding (IIW)

AT THE invitation of the American Council for the IIW, the fourteenth Annual Assembly of the IIW was held in New York from 11th to 18th April, 1961. This was the first of the Institute's Assemblies to be held outside Europe and it was attended by more than 500 participants from 22 countries.

Programme

The programme of the Assembly included opening and closing meetings of the Governing and Executive Councils of the IIW as well as four sessions of each of the fifteen technical Commissions. At these sessions many reports, some of which will be issued for publication, were discussed.

New Member Country

The Governing Council elected to membership of the IIW the Israel Institute of Metals. This election brings the number of member countries of the IIW to 29.

Spring Meeting of the American Welding Society (AWS)

No public session or lectures were organised during the IIW Assembly because it overlapped with the Spring Meeting of the AWS, which was held from 17th to 21st April. All IIW participants were invited to attend this meeting, the programme of which included, as well as a banquet, plant tours and the Welding Exposition, and the presentation of numerous papers; nine of these were given by non-American members of nine of the Commissions of the IIW and dealt with aspects of the work of the Commissions.

In addition, the AWS chose, from among names which it asked the IIW to put forward, Mr. H. Granjon (France) to give the AWS Adams Lecture for 1961 and Professor N. N. Rykalin (USSR) to present two papers to the AWS in its Educational Lecture Series.

Canadian Council of the IIW

The Assembly was organised by the AWS with the support of the Canadian Council of the IIW. On 20th April, this Council organised, for the benefit of non-American members of IIW, an expedition to Canadian plants in the Niagara Falls area.

Future Assemblies

The next Assembly of the IIW will be held in Oslo, Norway, from 25th to 30th June, 1962. The Governing Council has accepted an invitation from the Finnish Welding Society to hold the 1963 Assembly in Helsinki.

Reports of Commissions – 1960

Chairmen's reports of the activities of Commissions of IIW following the Annual Assembly held in Liège from 13th to 17th June, 1960. Reports for Commissions I–VII were given in the Spring number of "International Welding."

Commission VIII: HYGIENE AND SAFETY

(*Chairman—Mr. L. André*—Sweden)

On the occasion of the 1960 Annual Assembly of the International Institute of Welding, Commission VIII met at Liège from June 13th to June 17th. Delegates were present from Belgium, Denmark, France, Germany, Netherlands, Norway, Poland, Sweden, Switzerland, United Kingdom, U.S.S.R. and Yugoslavia. Experts and observers were present from Belgium, Germany and Sweden. The Commission did not hold any other meeting in 1960.

The most important decision taken by Commission VIII at Liège concerns transmission factors expressed as a percentage for eye protective filters. This decision is a result of a comprehensive investigation by the Commission, an investigation which was very difficult because of the various opinions expressed about these figures and the different values for these factors used in several countries. The factors decided on are shown in the following table.

Transmission factors expressed as a percentage for eye-protection filters

Shade No.	*Ultra-Violet*		*Luminous*		*Infra-red*
	313nm maximum	*362nm maximum*	*maximum*	*minimum*	*maximum*
1	0·1				
2	0·1				
3	0·1	1·0	18	8·5	10
4	0·1	1·0	8·5	3·2	8·0
5	0·03	0·3	3·2	1·2	6·0
6	0·03	0·3	1·2	0·45	4·6
7	0·01	0·1	0·45	0·17	3·5
8	0·01	0·1	0·17	0·060	2·5
9	0·01	0·1	0·060	0·023	1·8
10	0·003	0·03	0·023	0·0085	1·2
11	0·003	0·03	0·0085	0·0032	0·8
12	0·003	0·03	0·0032	0·0012	0·5
13	0·003	0·03	0·0012	0·00045	0·3
14	0·003	0·03	0·00045	0·00017	0·3

Note—nm = nanometer = 1×10^{-9}m = 10 Å

The Commission accepted the figures shown in the table above but found it necessary to point out that these figures were given as the limits of allowable transmission factors. The recommended values of these factors are in agreement with the results of medical and physical investigations on the action of radiation —both visible and invisible—on the human eye.

Having reached this decision, the Commission recommended, in a resolution approved by the Governing Council, that these data be transmitted to ISO to be used as a basis for the study of an international recommendation.

At the Opatija meeting in 1959, it had been agreed that Commission XII "Special arc welding processes" should establish a Working Group "h" in order to co-operate with Commission VIII in collecting information and quantitative data with regard to health and safety in special arc welding processes with a view to the compilation of a supplement to the Handbook on Health and Safety prepared by Commission VIII. At the meeting at Liège, Commission VIII decided that a new Sub-commission should be established, under the Chairmanship of Dr. Granjon (France), to proceed with the study whilst maintaining contact with the Working Group "h" of Commission XII.

Finally, Commission VIII reached a decision concerning proposed modifications, suggested by the Chairman of Commission I (Gas Welding), to Document IIS/IIW–58–60 (ex doc. VIII–109 (5)–58) "Handbook on Health and Safety in Welding and Allied Processes", the French version of which was ready for circulation by the Scientific and Technical Secretariat. In a resolution adopted by the Governing Council Commission VIII, having accepted some of these modifications, expressed the wish that publication should not be delayed and its intention to begin at once to prepare a revised and enlarged edition of the document in question.

The agenda for the next meeting in New York, U.S.A., will contain the following items:

1. Health and safety in special arc welding processes
2. Head and skin protection
3. Amount of welding fumes behind helmets and handshields
4. Colour of the walls etc. in welding workshops
5. Multilingual list concerning various personal protective equipment used in welding
6. Other questions.

Commission IX: BEHAVIOUR OF METALS SUBJECTED TO WELDING

(*Chairman—Prof. K. Rühl*—Germany)
(*Vice-Chairman—Dr. H. G. Geerlings*—Netherlands)

This report deals with the work done by Commission IX since the Opatija Assembly in June/July 1959.

The Liège meetings were attended by delegates, experts and observers from 21 countries. Since the Opatija Assembly, a meeting of Sub-commission "D" (Chairman—Mr. Roberts—United Kingdom) had taken place on 3rd November 1959, in London. The questionnaire for collecting information on brittle fracture failures in service and two supplementary reports were then amended (Doc. IIS/IIW–61–60, ex doc. IX–D–14–60, IX–D–15–60, IX–D–16–60). A meeting of the Working Group for the study of the mechanics of brittle fracture was held on 4th April, 1960 in Liège.

The following subjects were dealt with at the Liège meeting:

1. Houdremont Lecture

Professor Soete (Belgium) presented a paper entitled "*Mechanical Aspects of Brittle Fracture*". In this paper a great number of tests on the brittle and ductile behaviour of different specimens are described. First, residual stresses resulting from heating were introduced in tensile bars, holes were drilled and notches were sawn out. Thus the effect of the sequence-residual stress followed by the introduction of defects or *vice versa* could be noted. Moreover cracks in notched test pieces were caused by fatigue loading and, if the cracks had a certain length, the test pieces were loaded to fracture. The tests were carried out on specimens in normalised and unnormalised condition. Furthermore, specimens similar to the first series were used, in which residual stresses could be set up and measured. The test pieces were cracked by fatigue and then the nominal fracture stresses, especially at low temperatures, were determined. Some of the test pieces were loaded after residual stresses had been set up.

Studies on the deformation of a cracked specimen and a survey of the possibilities of avoiding brittle fracture completed the paper.

2. Bibliographical report

Mr. Lagasse (Belgium) distributed and explained a report (Doc. IX–272–60) listing the papers on brittle fracture published during the year.

The Commission adopted a resolution recommending that this report by Mr. Lagasse be published. This resolution was approved by the Governing Council.

3.

Mr. Boyd (United Kingdom) reviewed the literature on the *metallurgical effects inseparable from residual stress* ("The Metallurgical Concomitants of Residual Stress" Doc. IX–260–60). This study is concerned with the residual stresses which arise directly from welding and with the changes which occur in the nature of a metal and affect its mechanical properties. It is shown that the residual stress due to welding cannot occur without plastic flow. Plastic flow in association with the temperature cycles of welding and the lapse of time produces strain-ageing and quench-ageing in mild steel. The embrittling effects are demonstrated both by the shift of the energy or crystallinity curves plotting the results of impact tests on notch specimens towards higher temperatures and also by the variation of the transition temperatures with the distance from the weld. A series of numerical results is given.

The Commission was of the opinion that these problems should be more closely studied. After a full discussion Mr. Boyd and Mr. Herbiet (Belgium) were asked to propose a Sub-commission or working group. The establishment of a working group of six members:

Mr. Boyd (United Kingdom)
Mr. Granjon (France)
Mr. Hartbower (U.S.A.)
Mr. Herbiet (Belgium)
Mr. Van der Veen (Netherlands)
Mr. Wiester (Germany)

was unanimously approved by Commission IX and was the subject of a resolution adopted by the Governing Council.

The working group will prepare a report for the meeting in 1962, insufficient time being available before the New York Assembly.

4. Questionnaire on weldability tests

Mr. Granjon submitted a draft questionnaire on the "*Study of Weldability Tests*" (Doc. IX–273–60). The purpose of this questionnaire is to gather information to make possible the classification of cracking tests.

Questions included, cover the name of the test, relevant publications, the description of the test, its main object and the field of application. The Commission adopted a resolution to circulate this questionnaire to member countries with a request for answers on tests used in their respective countries.

5. Work of Sub-commission B—Weldability of steels in relation to transformation characteristics—(*Chairman—Mr. Granjon*)

At the Opatija meeting Commission IX, on the proposal of Sub-commission "B", adopted a resolution that data should be collected and published on continuous cooling transformation curves for weldable steels. Mr. Granjon reported that he has received reports from the Soviet delegation (Doc. IX–263–60, N. N. Rykalin and M. H. Sorsorov: "Particularités de la transformation de l'austénite et de la formation de fissures 'froides' lors de soudage par fusion" ("Particularities of the transformation of austenite and of the formation of 'cold' cracks in fusion welding") and the Japanese delegation (Doc. IX–262–60 "Continuous Cooling Transformation Diagrams of Steels for Welding and their Application" by Harujiro Sekiguchi and Michio Inagaki). Contributions have been received on the CTS test from several countries. Lack of time prevented the Sub-commission from preparing a summary of these documents, but a report based on them will be submitted at the next meeting of Commission IX in New York.

6. Work on mechanics of fracture

A detailed report on "*Brittle fracture mechanics in relation to transition temperature behaviour*" has been prepared by Dr. Wells (United Kingdom) and the Fracture Mechanics Working Group for submission to Commission IX (Doc. IX–265–60), and has been circulated. Dr. Wells made a brief verbal report on this document.

The report first emphasises the difficulties still involved in clarifying the correlation between different tests and between test specimens and welded structures as far as brittle or ductile behaviour is concerned. Subsequent chapters show the effects of the state of stress and notches, elasticity, plasticity and specimen shape, the influence of grain size, temperature and straining rate while the phenomena associated with microcracking and cleavages are illustrated. Discussions follow concerning more complex cases of intergranular fractures in micro-structures, of fracture in large specimens and of fracture propagation. The report draws the following conclusions: "In an attempt to trace the source of the differences (of the transition temperatures obtained with different specimens) it could therefore be concluded as likely to be

most profitable at the present time to pursue static yielding and low temperature fracture testing on small plain specimens. While test programmes using these techniques are already in existence ... it cannot ... be assumed that the objectives ... are the same as those now discussed ... It would be wise to ensure that a programme with the specified objective be now commenced ...".

Commission IX fully supported this conclusion. After discussion, the Commission agreed unanimously to the transformation of this working group into a Sub-commission (Sub-commission E) to organise and encourage research in the member countries in the field of fracture mechanics. The proposed membership of the Sub-commission, subject to the agreement of the national delegations concerned, is as follows:

Dr. Wells, Chairman (United Kingdom)
Prof. Kochendörfer (Germany)
Mr. Lagasse (Belgium)
Prof. Munse (U.S.A.)
Mr. Plateau (France)
Mr. Sleeswyk (Netherlands).

A resolution to this effect was adopted by the Governing Council.

Mr. Schnadt (Switzerland) distributed comments (IX–274–60) on previous remarks by Prof. Rühl (Doc. IX–242–59 "Influence of triaxiality") and Doc. IX–265–60, in which, in particular, he questioned the priority of some formulae, mentioned in these documents.

7. Contribution from Mr. Schnadt

Mr. Schnadt presented verbally a report that had already been distributed as Doc. IX–267–60 "Définition et signification pratique des droites thermovectoniques des aciers et soudures". In it the actual stresses and embrittling effects and the main characteristics of stress and strain are first shown. Then new notions (Antitempérature, Véloganie de Déformation) are introduced and the tendency to brittle behaviour of a steel is scientifically defined, use being made for this purpose of the Basic Diagram of H. M. Schnadt which is already known. A new Amsler-Schnadt-pendulum-hammer allows impact-testing of specimens at two different velocities. If we apply a system of co-ordinate axes, in which the x-co-ordinates (abscissa) are the temperature (or the anti-temperature as the case may be) and the y-co-ordinates (ordinates) are the loading velocity and thereby the strain rate in a logarithmic scale, all the associated values x and y valid for a particular energy absorption form a straight line. If we assess the temperatures at which the energy absorption for the two loading velocities of the Amsler-Schnadt pendulum hammer reaches a particular value (for instance 7 kgm/cm^2), we have two points of the line and can plot it. If, for the relevant temperature, this line goes through a point above a particular value of the y-co-ordinate, the steel, Mr. Schnadt believes, will not be liable to crack initiation, and if the line goes through a point above a second, higher value, the steel will not be liable to crack propagation. This means, that crack initiation will be prevented if the steel, in tests with the lower velocity of the Amsler-Schnadt pendulum hammer, has at least an energy absorption of 7 kgm/cm^2 (in the "cohéracie" specimen).

Crack propagation will not occur if the steel has the same energy absorption at a higher velocity (which is not the same as the higher velocity of the Amsler-Schnadt pendulum hammer). A criticism of facts and hypotheses concerning the brittle behaviour of steel completes the report.

8. Problems of corrosion

Mr. Zelders (Netherlands) presented a verbal report on problems of corrosion in steel welds. A written document will be distributed later. Several members of Commission IX expressed an interest in these problems.

A working group has therefore been formed to study the corrosion of steel welds. The members of this group are:

Mr. Zelders (Netherlands)—Chairman
Mr. Audigé (France)
Mr. Dancevic (Yugoslavia)
Mr. Rädeker (Germany)

and a British delegate to be appointed.

The Governing Council took note of the resolution submitted to it in this connection.

9. Contribution from the Japanese delegation

The Japanese delegation presented three papers:

Continuous Cooling Transformation Diagrams of Steels for Welding and their Application (Doc. IX–262–60) by Harujiro Sekiguchi and Michio Inagaki
Statistical Investigations on V-Charpy-Transition Curve and Fluctuation of Impact Data (Doc. IX–268–60) by Masao Yoshiki
Japanese Comments on Rühl's Proposal about the Classification of Structures (Doc. IX–280–60).

The first document was illustrated by a verbal report by Mr. Inagaki. This document has already been mentioned in connection with the work of Sub-commission B (see item 5 of this report) and will be used for the report summarising its work which Sub-commission B is to present at the New York Assembly.

The second paper mentions the paper by Mr. Herbiet and Mr. Descovich (Italy), "Contribution to the study of an acceptance method of testing for weldable steels C and D using the V-notch Charpy-Test on the basis of a conventional specimen" (Doc. IIS/IIW–49–60, ex doc. IX–184–57). Statistical investigations of this kind on structural steels produced in Japan were held necessary and carried out by Commission IX of the Japan Institute of Welding. Data obtained from 261 plates were collected and analysed. For a range of temperatures above and below the temperatures T_{20} (temperature for an energy absorption of 20 ft-lb. (2·8 kgm)) and T_{35} (temperature for an energy absorption of 35 ft-lb. (4·9 kgm)), the mean and standard deviations were calculated for each temperature T and related to the values $T–T_{20}$, or $T–T_{35}$. The curve for the relationship between the mean of energy and the standard deviation for mild steel (addition of the data for rimmed, semi-killed and killed steels) may be plotted. The curve shows first the validity of adopting 0·8 kgm as standard deviation for the 20 ft-lb. criterion, as has been found by Herbiet and Descovich. Secondly, it shows that a standard deviation of 1·2 kgm may be considered appropriate for the 35 ft-lb. criterion. On this basis, the value of the

confidence interval and sequential test for the 35 ft-lb. criterion was determined by the Herbet-Descovich method. Some further tests were carried out on high tensile steel.

The third paper concerns the classification of structural parts. It is referred to under item 11 of this report.

10. Contributions from the American delegation

Four members of the United States delegation gave an extensive review of research in the U.S.A. on the problem of fracture.

In view of the very comprehensive but condensed character of these reports, it seems out of place to give here a substantial summary of the subjects dealt with in them, as attempted for the other items, particularly since accounts of the work in question have already been published. Consequently, only a short summary of the topics dealt with is given below.

Professor Cohen presented a progress report on the research programmes at the Massachusetts Institute of Technology on the mechanism of brittle fracture and the phenomena associated with different types of fracture (for some of his results, see the paper "*Initiation of Cleavage Microcracks in Polycrystalline Iron and Steel*" by G. T. Hahn, B. L. Auerbach, W. S. Owen and M. Cohen in the book "*Fracture, Proceedings of an International Conference, April 12–16, 1959*").

Professor Hall reported on the work being done at the University of Illinois on tests on brittle fracture of wide plates. The report (Doc. IX–259–59) "Studies of the strain distribution in wide plates during brittle fracture propagation", by S. T. Rolfe, T. N. Lynam and W. I. Hall, has been published as report SSC–118, Fourth Progress Report of Project SE–137, to the Ship Structure Committee. A condensed report, "A Summary of Recent Brittle Fracture Mechanics Research", University of Illinois, Urbana, Illinois, U.S.A., has been distributed (Doc. IX–279–60).

Professor Mylonas summarised investigations, in progress at Brown University, Providence, R.I., utilising tests into which prestrain damage is introduced. These investigations are reported in the papers by Professor C. Mylonas, "*Static Brittle Fracture Initiation at net Stress 40% of Yield*" (*Welding Journal* Research Supplement, October 1955), and "*Prestrain, Size and Residual Stresses in Static Brittle-Fracture Initiation*" (*Welding Journal* Research Supplement, October 1959).

Mr. Hartbower gave a report on current work at the Watertown Arsenal on the cruciform cracking test and on the weldability and notch sensitivity of high strength alloy steels.

11. Classification of structural parts

At the Opatija meeting Professor Rühl presented a document (Doc. IX–246–59) dealing with method for the selection of an adequate steel for structural parts and outlining the German recommendations for classification of structural steelwork. Professor Rühl completed this report by some brief fundamental remarks (Doc. IX–264–60). As contributions to the discussion of these problems Mr. Audige presented a note (Doc. IX–271–60) by the French delegation and Dr. Inagaki a report mentioned in item 9 of this report (Doc. IX–280–60).

Both papers are concerned with the application of the German recommendations to other structures and the authors have found that in general the method in question may be practicable, though modifications to it are necessary. As already mentioned, a critical study of the fundamental principles is needed.

Professor Bierett (Germany) gave a report on a different but similar method, based on his own proposal for, and experience in, classifying structural parts.

The Chairman intimated further that Dr. Guerrera (Italy), as Chairman of Commission XV (Fundamentals of Design and Fabrication for Welding), had drafted a report on document IX–246–59 and submitted this to Commission XV for discussion. Commission XV had resolved to set up a Working Group to study this problem from the viewpoint of that Commission. Professor Bierett had been asked to be a member of this Group.

Commission IX resolved unanimously that the classification of structural parts is closely connected with the establishment of recommendations on steels and that the Sub-commission under the chairmanship of Mr. Bonhomme (Belgium) should be resuscitated to study these problems as a whole; the setting up of this Sub-commission, which will be "Sub-commission F", was the subject of a resolution adopted by the Governing Council. A proposal for its membership was not made at the meeting, but Mr. Bonhomme has in the meantime proposed the following composition:

Mr. Audigé (France)
Prof. Bierett (Germany)
Mr. Boyd (United Kingdom)
Mr. Hebrant (Belgium)
Mr. Vanderbeck (U.S.A.)

and a Japanese delegate to be appointed.

12. Problems raised by the welding of thick materials

Mr. Lanyi (Czechoslovakia) reported verbally on a paper, previously circulated, by Professor Cabelka "Les connaissance nouvelles dans le domaine de la soudabilité des constructions lourdes" ("New knowledge concerning the weldability of heavy constructions") (Doc. IX–266–60). In his paper Professor Cabelka first draws attention to the detrimental effect of impurities, especially oxygen, on the qualities of welds. The influence of oxygen has been demonstrated by new investigations. The problem is particularly important as regards the welding of thick materials which, with the development of adequate welding processes, such as slag welding, is, from an economic viewpoint, very important for large structures. Professor Cabelka recommends that large constructions should be executed by welding together parts forged from the lower section of ingots, using the electro-slag process. Application of the vacuum melt method is considered of no importance. In order to obtain welds of pure metal, he proposes buttering the edges using the electro-slag process.

It has been found that the grain size of the weld metal does not only depend on temperature, elements added (Ti, Al), and the cooling rate, but also on the difference between the temperature of the solid and the liquid state of the metal. This difference is influenced by the impurities, oxygen, nitrogen, and so on.

By applying appropriate method influencing the difference in temperature between the solid and liquid state, the mechanical properties and the ductility may be improved.

13.

In a resolution approved by the Governing Council, Commission IX again emphasised the necessity for circulating the questionnaire prepared by Sub-commission D (Chairman—Mr. Roberts, United Kingdom) regarding *the collection of data on brittle service fractures* (Doc. IIS/IIW-61-60, ex doc. IX-D-14, 15 and 16-60).

14.

Professor Westendorp (Netherlands) gave an account of the problem of the *weldability of light alloys*. It has not yet been possible to begin joint work by the proposed Working Group, but in future more rapid progress will be made with the work.

15.

Professor Rykalin (U.S.S.R.) suggested the collection of information available on *heat flow in welding*. It was agreed that this problem is an important one, but of a highly theoretical nature, and that only specialist experts can do useful work in this field. The member societies will be requested to nominate members for a Working Group under the chairmanship of Professor Rykalin to consider the matter. This decision was the subject of a resolution which was noted by the Governing Council.

16. Further work of the Commission at the Liège meeting

Two suggestions of the Swedish delegate, Mr. Erikson (Doc. IX-269-60, "S. E. Erikson, P. Matton-Sjöberg: Correlation between notch-ductility at sub-zero temperatures and non-ageing properties" and Doc. IX-270-60 "S. E. Erikson, P. Matton-Sjöberg: Suggestion concerning recommendations for welding low-alloy structural steels") will be considered by the Boyd-Herbiet Working Group and Sub-commission B respectively.

It was stated that the distribution of documents is to be improved in order to enable the members of Commission IX to study them before the discussions at the meeting.

The Chairman asked all the members who had taken part in the discussions to send him a written summary of their comments for inclusion in a document to be circulated to the members of the Commission. He further requested that proposals for the agenda for the 1961 meeting should be submitted to him by January 1961.

Commission X: RESIDUAL STRESSES AND STRESS RELIEVING

(*Chairman—Dr. R. Weck*—United Kingdom)

Problems related to residual stresses in light alloy structures

The delegates had been invited at Opatija (Yugoslavia) in 1959 to make enquiries in their own countries regarding any problems which might exist in connection with residual stresses in light alloy structures and which should be considered by the Commission. The Chairman had only received one communication from one country (Canada) which did not define any problems which appeared to require investigation by the Commission; consequently the Commission approved a resolution (Resolution No. 1), which was noted by the Governing Council, to the effect that there were not at the present time any problems requiring investigation.

Stress relieving of alloy steels

Since document X-136-56 "Investigation of stress relieving of special steels" was issued for publication, further and extensive data had been collected. It appeared in the discussion that the original document had not been published in many countries despite the fact that the information contained in it was of great importance, particularly to the fabricators and users of pressure vessels in these materials. The Commission therefore decided that Mr. Tummers (Netherlands) should prepare a completely new report for publication which will include all the previously published data and, in addition, those which had been obtained during the last four years. Dr. Benson (United Kingdom) who had certain reservations with regard to the applicability of data obtained by relaxation tests in torsion, would be invited to prepare a note for publication as an integral part of the report.

The document will be prepared by Mr. Tummers in both languages and will be in the hands of the Scientific and Technical Secretary by January 1961. It will include information obtained by Dr. Brozzo (Italy) on forged Mn-V, Mn-Mo-V steels and cast Mo-Cr-V steels. (Document X-248-60 "Relaxation tests on alloy steels: Mn-V (forged), Mn-Mo-V (forged), Mo-Cr-V (cast)"). The Commission also recommended the publication of the theoretical work on stress relaxation tests carried out by Dr. Brozzo (Italy) (Document X-229-59 "Observations on the results of torsion relaxation tests performed on some types of heat resisting steel").

Extensive additional tests had been carried out on 1% Cr-½% Mo steel and 5% Cr-½% Mo steel in order to verify whether the previous findings regarding the different slopes of the stress relaxation curves for these steels could be confirmed. The differences in slope were in fact confirmed but another interesting and significant discrepancy was revealed. Although the tests were carried out for each steel on test specimens cut from the same bar but tested in a number of different countries, there was reasonable agreement in the results obtained in Belgium, Germany, Sweden and Netherlands but the results obtained in the U.K. differed. Basically, the reason for the discrepancy is a difference in the determination of the 0·2% proof stress, on which of course the relaxation tests are based. Another discrepancy of a similar character was found in the results obtained in Germany on the 5% Cr-½% Mo steel which differed from those obtained in other countries. The Commission agreed that there is an urgent need for an internationally accepted standard for determining the 0·2% proof stress. It was also agreed that the data obtained in the U.K. and in Germany should nevertheless be included in the report to be prepared by Mr. Tummers and that attention should be drawn to the probable cause of the discrepancy.

Relaxation under multiaxial stress conditions

At the meeting in Opatija the Belgian delegate, Mr. Bihet, had expressed the view that results obtained for stress relaxation, as a function of time and temperature for conditions of torsion, might not necessarily be applicable if the conditions of stress were more complex, that is, if there were stress concentrations and/or multiaxial stresses. A series of tests were carried out by Dr. Gunnert (Sweden) on specimens in the form of cubes which were quenched from a temperature of 500°C. As a result, triaxial stresses were introduced in the interior and these were measured. The tests proved that the efficacy of stress relieving heat treatments was not diminished if the stresses were triaxial (Document X–246–60 "Influence of stress annealing in a triaxial stress system in the internal parts of weld metal", by Dr. R. Gunnert). The same conclusion was reached independently by Mr. H. Schnadt, in a theoretical treatment of the same problem (Document X–257–60 "Mathematical treatment of the experimental results obtained by R. Gunnert concerning the stress annealing on a triaxial stress system").

As a result, the Commission adopted resolution No. 4, which was noted by the Governing Council.

Effect of grain size on stress relaxation

A document (X–251–60 "Effect of the grain size on stress relaxation") was presented by the Dutch delegate, Mr. Tummers, which showed that grain size did not seem to affect stress relaxation characteristics. Since, however, there is a change in proof stress with change in grain size, the comparative tests carried out by Mr. Tummers were based on different proof stresses. It follows that the two effects—grain size and proof stress—may neutralise each other, and it must be concluded that two steels of different grain size but the same proof stress would exhibit different stress relaxation characteristics.

Measurement of residual stresses

Two documents, X–245–60 "Cracks in the root of multi-pass arc welds caused by residual stresses" and X–247–60 "The relation between stress and strain in stress measurements according to the trepanning method, taking into consideration the uneven stress system below the surface of the material" were discussed, both having been submitted by the Swedish delegate, Dr. Gunnert. In X–245–60 the author shows that cracking of the root of a butt weld may be associated with the study of residual stress at that point. In X–247–60 the author considers certain difficulties arising, in the use of the trepanning method for the determination of triaxial stresses, from the stress relaxation in one part of the stress relaxation in another part of a test piece.

Effects of residual stresses on brittle fracture

Extensive discussion took place on two American papers, X–226–59 "Prestrain, size and residual stresses in static brittle fracture initiation" and X–242–60 "Exhaustion of ductility of E-steel in tension following compressive prestrain" presented by Mr. Mylonas (U.S.A.) and concerned with the problem of initiation of low stress brittle fracture from the bottom of a notch. These papers showed that low stress brittle fracture could be induced if the tensile ductility of the material was exhausted at the bottom of a notch by severe plastic deformation in compression. The Commission agreed that the same phenomenon had been shown to be operative in the tests carried out by Dr. Wells (United Kingdom) on notched wide welded plates and in the more recent tests carried out by Professor Soete (Belgium) and reported in the Houdremont Lecture delivered at Liège. There was general agreement that the mechanism proposed by Dr. Wells in 1953 for fracture initiation was essentially the same mechanism as that proposed by Professor Mylonas, since exhaustion of ductility at the bottom of a notch could be produced by welding as readily as by severe plastic pre-straining without welding.

The role of residual stresses was important in propagating a fracture once started at low externally applied stress. The Commission felt that what constitutes exhaustion of ductility and its measurement for different materials required further investigation, and this decision was embodied in resolution No. 5, adopted by the Governing Council which reads as follows:

In addition to the continuance of the work on residual stresses, the Commission attaches great importance to the pursuance of two related lines of research to which it would like to see a greater effort devoted.

(1) The determination of the strains occurring at the bottom of a sharp notch or a natural crack in a plastic work hardening material as a function of applied load. In this context the Commission particularly welcomes the work by Professor Soete (Belgium) and his collaborators referred to in the Houdremont Lecture using the "moiré" pattern as well as other methods such as the birefringent coatings method. The Commission would like to see this work intensified.

(2) The quantitative experimental determination of what constitutes exhaustion of ductility of a material, as a function of the previous history of the material, and its dependence on composition and metallurgical structure.

Effect of residual stresses on fatigue

Discussion of two U.S.S.R. papers—X–239–59 "Effect of residual stresses on vibration strength of weldments", and X–255–60 "Schéma de calcul pour l'évaluation de la résistance à la fatigue des éléments soudés, compte tenu des contraintes résiduelles et de changements de propriétés du métal de base provoqués par le soudage" ("Diagram for calculations to evaluate the fatigue strength of welded assemblies, account being taken of residual stresses and changes in the properties of the base metal as a result of welding") was deferred at the request of the author, Professor Okerblom, who was unable to attend the meeting at Liège.

The Commission gave further consideration to certain problems arising from the application of the method of spot heating for the improvement of the fatigue resistance of welded constructions, this matter having been referred back to Commission X from Commission XIII; in this connection the following resolution was adopted and approved by the Governing Council:

The Commission accepted the proposal made by Commission XIII that it should include in its own programme the following three problems connected with the residual stresses resulting from spot heating of welded constructions with the object of improving fatigue resistance:

(1) The calculation and/or measurement of residual stresses due to spot heating (and local compression) considering all possible variables.
(2) Study the effect of spot heating on material properties other than fatigue (brittle fracture).
(3) Study the effect of time on the persistence of the influence of residual stresses.

Colloquium on the effect of residual stresses on stability

The last meeting of the Commission was devoted to a colloquium. The following five papers had been received:

"The effect of residual stresses on the behaviour of continuous structures", by M. R. Horne, Sc.D. (United Kingdom).
"Residual stress and the instability of axially loaded columns", by Lambert Tall, Alfons W. Huber and Lynn S. Beedle (U.S.A.).
"Influence sur la charge critique de flambement de colonnes en double TE des tensions résiduelles introduites par des cordons de soudure déposés sur les bords dessemelles" ("Influence of residual stresses resulting from weld seams on the edge of flanges on the critical load for buckling of double T columns"), by H. Louis, Ch. Massonet, P. Guiaux, P. Hallet and G. Kayser (Belgium).
"The influence of residual stresses on the instability problems", by H. Kihara and Y. Fujita (Japan).
"Action des contraintes résiduelles créées par le soudage sur la résistance générale et locale des éléments de constructions soudées" ("Action of residual stresses set up by welding on the general and local strength of parts of welded construction"), by N. O. Okerblom (U.S.S.R.)

These were presented by Professor H. Louis and Professor Ch. Massonet who acted as rapporteurs. After discussion, which was opened by Professor Campus (Belgium) and in which Professor M. R. Horne, Professor Y. Fujita, Professor Bornscheuer (Germany), Mr. Dechaene (Belgium), Professor Louis and Professor Massonet took part, the meeting adopted the following resolution which was noted by the Governing Council:

(1) The most important conclusion of this colloquium is that residual stresses reduce significantly the stability of axially compressed columns, especially in the case of I or cruciform profiles fabricated by welding; this fact must be made known to designers.
(2) From these results, the possibility of increasing the collapse load of columns by injecting in them suitable residual stresses which counterbalance the deleterious effect of stresses arising from the mode of fabrication; sometimes, in the case of box sections, the favourable residual stresses are obtained directly by the fabrication process.
(3) Care must however be exercised in the manipulation of stress states produced artificially; their creation may be accompanied by defects and metallurgical alterations which could initiate brittle failures, especially when the structure does not sustain any live load.
(4) It is necessary to resist the temptation to employ, in the case of rigidly framed plates or of structures made from such plates, residual stress distributions which increase the critical load of linear buckling. In fact, this critical load is not an adequate measure of the actual ultimate load of the structure. Consequently, any proposal of this kind should be supported by collapse tests.
(5) Generally speaking, the theoretical advances recognised during this colloquium should be backed by extensive tests, carefully programmed and carried out under realistic conditions, that is with initial imperfections and eccentricity. Attention should be directed also towards the same problem in relation to fabricated tubular or box sections.

The following documents, in addition to those mentioned in the present report, were circulated to the Commission:

X-238-59—Discussion of Document X-226-59 "Prestrain, Size and Residual Stresses in Static Brittle Fracture Initiation by C. Mylonas", by L. J. Larson (U.S.A.)
X-244-60—"Stress-Relief of Alloy Steels", by G. E. Tummers (Netherlands).
X-249-60—Letter concerning Document X-244-60—"Stress-Relief of Alloy Steels", by G. E. Tummers (Netherlands).
X-250-60—"Mathematical Interpretation of the Relaxation Curve", by G. E. Tummers (Netherlands).
X-258-60—"Discussion of Document X-226-59 by C. Mylonas", by H. Kihara (Japan).

Commission XI: PRESSURE VESSELS, BOILERS AND PIPELINES

(*Chairman—Ir. J. J. P. Cattel*—Netherlands)

Delegates from the following countries attended the meetings held by Commission XI at the Annual Assembly of the International Institute of Welding in Liège: Belgium, Czechoslovakia, France, Germany, Italy, Netherlands, Sweden, Turkey, United Kingdom, United States, U.S.S.R. and Yugoslavia. Sixteen experts accompanying the delegates and sixteen observers were also present at the meetings.

The Commission had not held any intermediary meetings since the 1959 Annual Assembly. Sub-commission A "Design details" met in London from 23rd to 25th February, 1960, and the Working Group "Stress relieving" met in Paris on 22nd April, 1960.

Document XI-41-60 "Fundamentals of design and fabrication for welding—Welding of reservoirs and pipelines in winter conditions", was submitted to the Commission by the Soviet delegation. As the subject dealt with in this document is not the exclusive concern of the Commission, it was decided to refer the document to Sub-commission B "Allowable Stresses", for study and advice regarding the other IIW Commissions to which it might be forwarded. With regard to the introduction of the welding of plastics into its terms of reference, the Commission considered that, though it would be appropriate for it to study the construction of reservoirs and the fabrication of pipelines in plastics it would be premature to take up this subject at once, in view of the still very limited number of uses of these materials in this field.

Sub-commission A "Design details"

Comments on Document XI-A-3-59 "Recommended welded connections for pipe systems—First draft" were the subject of discussions at the London meetings in February 1960 and resulted in an amended draft to be discussed by the Sub-commission towards the end of the year. In addition, recommendations are being studied concerning first, clad and lined vessels and second, vessels welded with deep penetration electrodes. A preliminary note on the latter subject has been prepared by the Swedish delegation (Doc. XI-A-4-60) and has given rise to comments from the German and French delegations (Docs. XI-A-5-60 and XI-A-6-60 respectively).

Sub-commission B "Allowable stresses"

Documents to be studied by the Sub-commission, based on Document IIS/IIW-9-58 (ex doc. XI-21-58) "A rational design procedure for pressure vessels" were completed too late for discussion by the Sub-commission. Consequently, it was agreed to present them first to Commission XI to obtain a general opinion on them. It was decided that two of these documents: XI-42-60 "Classement des contraintes en trois catégories" (Classification of stresses into three categories) and XI-44-60 "La corrosion de l'acier sous contrainte" (The corrosion of steel under stress) would be transmitted to the Sub-commission, members being asked to send in their comments so that account may be taken of them when these documents are being studied. With regard to the third document, XI-43-60 "Electrochemical investigation of corrosion fatigue of steel and methods of protection", the Commission shared the opinion of the Sub-commission Chairman that this document does not meet the needs described in Document IIS/IIW-9-58; in a resolution approved by the Governing Council, the Commission proposed, therefore, that Document XI-43-60 be transmitted to Commission XIII (Fatigue testing). The Sub-commission showed much interest in the photo-elastic tests now being carried out in the United Kingdom on models of drum heads: the results of this research cannot yet be published.

Working Group "Stress relieving"

Document XI-45-60 "On the desirability of stress relieving in welded pressure vessels" is a revised version of the former document XI-32-59 which was the subject of comments which were subsequently studied by the Working Group.

In a resolution approved by the Governing Council, the Commission recommended Doc. XI-45-60 for publication in order to obtain as many observations as possible on it; the Commission reserves the right to study the document again at a later date.

Working Group "Non-destructive testing"

The decision made in Opatija to prepare a fresh draft of Document XI-31-59 "Radiographie des soudures de chaudières et de récipients à pression—Première partie" ("Radiography of welds of boilers and pressure vessels—First part"), to which it had seemed desirable to make a certain number of amendments, caused some delay in the work of this Group. It intends to draw up a new draft and to this end, has invited both the Italian and the Soviet delegations each to appoint a representative to help it in its task.

In the course of the meeting, Commission XI was informed of the resolution adopted by Commission V (Testing, measurement and control of welds) in answer to the question asked by ISO/TC 11 "Unification of boiler codes" on the radiographic image quality required for welds in pressure vessels. In spite of certain reservations expressed by a few delegates, it was decided, since an investigation by Commission XI would result in further delay, to ask Commission V to recommend the immediate transmission of this reply to ISO. With regard to the importance of radiographic inspection of butt welds in thick pressure vessels Commission XI, in a resolution adopted by the Governing Council, asked Commission V to extend their study of image quality to thicknesses greater than 2 in. (50 mm) and, if possible up to 4 in. (200 mm).

Working Group "Design practice"

In Document XI-46-60 "Design practice in four European countries", the Working Group gave a first outline of the work which it expects to carry out. This document is not yet complete, however, and during a short meeting held by the four members of the Working Group in Liège, the final form of the document, which will ultimately be presented to the Commission, was discussed. The Commission has not discussed the document in its present form.

Document XI-47-60 "Survey of the activity of Commission XI" ("Coup d'oeil sur les activités de la Commission XI") lists the activities of the Commission since its establishment. Several small amendments were proposed and the document was considered as a valuable guide to the Commission's work.

In accordance with a recommendation in the Bye-Laws of the IIW, the Commission appointed Mr. Sluis (Netherlands) to succeed Dr. Carlson (United Kingdom) as Vice-Chairman; the Commission took the opportunity of paying tribute to Dr. Carlson for the work he had accomplished and expressed their gratitude to him for having agreed to continue to collaborate in the activities of the Commission and, particularly, for undertaking the Chairmanship of Sub-commission B.

During the last session, some members of Commission XI expressed regret about the time lapse between the Commission's approval of a document for publication by the IIW and the actual publication of the document (*e.g.*, Document IIS/IIW-30-59 (ex doc. XI-26-58) "Recommended welded connections for pressure vessels"). It was recommended that bearing in mind the necessity of editing the texts, the procedure followed should be speeded up as much as possible.

At the close of the meeting, the Soviet delegate proposed that the Commission should consider studying the welding of high pressure pipelines (see Doc. XI-53-60 "Efficient methods and rational organisation of welding in the construction of high pressure pipelines"—"Méthodes efficaces et organisation rationnelle du soudage dans la construction des canalisations à haute pression"). Here again, the question was raised whether the subject was outside Commission XI's terms of reference, as it is far removed from its present work. For this reason, in a resolution adopted by the Governing Council, the Commission asked the Council to consider whether, arising out of the proposal of the Soviet delegation, a special session could be organised at which the problems raised in Document XI-53-60 would be discussed.

Commission XII: SPECIAL ARC WELDING PROCESSES

(*Chairman—Mr. Komers*—Germany)

General matters and organisation of the Commission

This report concerns the work of Commission XII from July 1959 to the Liège Annual Assembly in June 1960.

At the Annual Assembly which took place in Liège from 13th to 16th June, 1960, Commission XII held 4 sessions at which 74 delegates, experts and

observers from 18 countries were present. Since the Opatija Assembly in 1959, Working Group "b" "Gas-shielded processes with or without flux (ferrous metals)" met in London on 1st April, 1960 and a meeting of Working Group "d" "Other special processes" was held in Paris on 16th March, 1960. Because of the limited time available at Liège and the urgency of the matters discussed there at the first session of Commission XII regarding the work of Sub-commission "A" "Submerged arc, continuous covered electrodes processes", this Sub-commission held an additional meeting during the 1960 Annual Assembly of the IIW, the results of which were discussed at the second session of Commission XII.

As regards the organisation of the Commission the Governing Council approved a resolution by which Working Group "b" was transformed into Sub-commission "B" the title of which is: "Gas-shielded processes with or without flux (ferrous metals)" and the Chairman of which is Mr. Leder (United Kingdom).

Working Group "g" "Terminology" was re-formed with all Sub-commission and Working Group Chairmen as members.

Commission XII has noted the agreement reached at the meeting of Commission Chairmen in January 1960 that the following processes should be added to its terms of reference: Electron beam welding—Rotating arc welding—Steam arc welding.

Furthermore, Commission XII has resolved not to include the welding of plastics in its working programme.

During the Liège sessions it was decided to hold intermediary meetings of the Sub-commissions of Commission XII in the Netherlands, at the end of October, or early in December 1960.

SUB-COMMISSION "A"—SUBMERGED ARC, CONTINUOUS COVERED ELECTRODE PROCESSES

(*Chairman—Dr. Wolff*—Germany)

The Chairman, Dr. Wolff, submitted a document entitled "New proposal on classification of welding wires and compositions used in the submerged arc welding process" (Doc. XII–72–60), which was discussed at some length, certain sections of it being amended (*e.g.*, as regards diameters, recommended weights, etc.).

Because of the Dutch criticism of the present proposal for the classification of fluxes, it was decided that, in a certain number of countries, control tests should be made, 3 fluxes being tested in each country in accordance with a scheme ensuring that all makes of powder would be represented. The results of these tests will be discussed at the December meeting of the Sub-commission.

SUB-COMMISSION "B"—GAS-SHIELDED PROCESSES WITH OR WITHOUT FLUX (FERROUS METALS)

(*Chairman—Mr. Leder*—United Kingdom)

As no agreement was reached at the main Commission meeting in Opatija, in 1959, regarding a new programme for Working Group "b", all delegates were asked to submit proposals by 1st October, 1959. Furthermore a meeting of Group "b" was arranged in London on 1st April, 1960 in order to discuss the problems involved. The results of this meeting are included in Doc. XII–85–60 "Report of Working Group 'b' for meeting at Liège 1960". At the Liège meeting, Working Group "b" was transformed into a Sub-commission with the following programme:

(*a*) To collect information on the types of wire used in different countries for the gas-shielded bare wire welding of mild steel, with a view to establishing a method of classification.
(*b*) To collect information from the different countries on recommended compositions for mixtures and maximum impurity levels of CO_2 and mixtures of CO_2 with other gases and on methods of gas supply.
(*c*) To examine the effect of welding current, arc voltage and traverse speed on the crack sensitivity of bare wire CO_2 butt welds, using the Boekholt cracking test. The details of this work will be drawn up by the Sub-commission.
(*d*) To make a preliminary study of water vapour shielded welding. A special report on work carried out up to date in the U.S.S.R. will be given by Professor K. V. Ljubavskij.

In addition to the above, the Sub-commission is working on a document setting out the objections to the Charpy-V-notch test with particular reference to its unsuitability for welds made by semi-automatic welding processes.

SUB-COMMISSION "C"—GAS-SHIELDED PROCESSES (NON-FERROUS METALS)

(*Chairman—Mr. Pirard*—Belgium)

Sub-commission "C" presented a report in Liège (Doc. XII–70–60) covering the results obtained since the last meeting as regards the different points of its working programme, the two main questions on which are the following:

(1) Mechanical properties of light alloy assemblies welded in inert gas atmosphere.
(2) The development of the argonarc welding process with consumable electrodes for the welding of thin material.

A substantial amount of information is available on the former item, from which it appears that, while certain aspects of the problem have been clarified, others are still being investigated. This applies particularly to the problem of fatigue tests and the study of the ways in which defects in the seam may influence the mechanical characteristics of the joints. With regard to the latter item, it is now obvious that the technique of welding thin material by the argonarc welding process with consumable electrodes is still in the development stage in many countries, but that it is worth while continuing studies in this field.

In view of the fact that a number of documents concerning the working programme of Sub-commission "C" were submitted too late, it was decided to examine them at a future meeting, when the new working programme for the 1961 Annual Assembly will be established.

Working Group "d"—Other special processes

(*Chairman—Dr. Cresswell*—United Kingdom)

Questionnaires covering stud welding, gas-shielded spot welding, arc cutting, electro-slag, fire cracker and enclosed welding were circulated during last year. Replies received from 10 different countries were discussed at a meeting of the Working Group in Paris, held on 16th March, 1960 and the findings compiled in

document XII–71–60. Detailed replies to the questionnaires were contained in documents XII–76–60 "Composite reply to questionnaires on stud welding, gas-shielded spot welding, arc cutting" and XII–78–60 "Composite reply to questionnaires on electro-slag welding, Elin-Hafergut (fire cracker welding) and enclosed welding" which show the stage of development and use of the processes in various countries. The following working programme was agreed upon in Liège:

(1) Methods of testing stud welds and their general metallurgical characteristics.
(2) Methods of testing gas-shielded spot welds and their general metallurgical characteristics.
(3) Electro-slag welding—weld properties, in particular impact strength and methods of improving it.
(4) Enclosed welding—stage of development and use of all new techniques—*e.g.* use of bare wire with gas shielding.
(5) Electron beam welding—stage of development and use.
(6) Rotating arc welding—stage of development and use.
(7) Welding and cutting aspects of plasma-flame processes.

Items 5 and 6 were allocated to Commission XII, for study, at the 1959 meeting of the Chairmen of Commissions.

SUB-COMMISSION "E"—INVESTIGATION OF METAL DEPOSITED BY ALL PROCESSES

(*Chairman—Mr. Magnusson*—Sweden)

In accordance with the working programme the work of Sub-commission "E" is proceeding steadily. With regard to "*mechanical properties of weld metal, deposited by different automatic welding processes*", tests as described in Doc. XII–48–59 "Tentative methods for testing weld metal deposited by automatic and semi-automatic welding (mild steel)", have been continued.

Results were reported in Doc. XII–E–1–60 (British delegation), XII–E–3–60=XII–57–60 (Italian delegation) and XII–E–4–60=XII–49–59 (Swedish delegation). Further reports on test results are expected from Belgium, France, Italy and the Netherlands.

Mr. Magnusson, Chairman of Sub-commission "E", hopes, next year, to be able to draw general conclusions regarding the suitability of the test procedure.

Investigations carried out in the Netherlands on the "*factors influencing the crack sensitivity of welds produced by submerged arc welding*" are reported in Doc. XII–E–7–60=XII–75–60 "The influence of some welding conditions into the crack sensitivity of welds made by automatic processes".

As to "*factors influencing porosity in welds*", the Sub-commission will study Doc. XII–E–8–60 "The effect of sulphur on porosity in automatic submerged arc welding", I. S. Sapiro (U.S.S.R.).

Working Group "f"—Power sources for special arc welding processes

(*Chairman—Mr. Moneyron*—France)

In 1960, Working Group "f" drew up a questionnaire concerning the utilisation of the different power sources for special arc welding processes.

The answers to this questionnaire should permit the compilation of a list covering the materials used in the various countries. Unfortunately, however, not all the answers were available at the Liège meeting, and the Chairman, Mr. Moneyron, hopes to have them by the New York meeting.

Working Group "g"—Terminology

(*Chairman—Mr. Walser*—Switzerland)

Although the Chairman, Mr. Walser, suggested the dissolution of this working group, the majority of delegates were of the opinion that it is important for it to continue in being, as new processes for which names have to be found and agreed upon are continually appearing.

It was therefore decided to re-form this Group with all Sub-commission and Working Group Chairmen as members. When new terms have been agreed upon by Group "g", they will be discussed by Commission XII whose decisions will be forwarded as resolutions to the Governing Council.

Working Group "h"—Health and safety in special arc welding processes

(*Chairman—Mr. Boekholt*—Netherlands)

In Doc. XII–74–60 a general survey was given of all data supplied and all reports available on "Health and safety in special arc welding processes". This document did not include information from every country. Three more reports are expected within a few months. They will be forwarded to Commission VIII (Health and Safety) as a supplement to Doc. XII–74–60.

The future programme of this Working Group can be summarized as follows:

(*a*) In co-operation with Commission VIII, the intention is to issue supplements to the "Handbook on health and safety in welding and allied processes" (Doc. IIS/IIW–58–60, ex doc. VIII–109–5–58) already drawn up by that Commission.
(*b*) It will be necessary to revise the Handbook from time to time to keep abreast of all technical developments in welding processes.

Various documents

In addition to the documents mentioned above, the following papers were distributed to the members of Commission XII:

XII–77–60 "Inert gas welding applied to the building of light alloy fast patrol boats in Japan" (J. Iwai, Japan)
XII–79–60 "The effect of discontinuities on the behaviour of aluminium welds" (Dutch delegation)
XII–80–60 "The CO_2/O_2 arc welding process with steel wire containing deoxidisers" (H. Sekiguchi, Japan).

Commission XIII: FATIGUE TESTING

(*Chairman—Mr. H. de Leiris*—France)

The agenda for the Liège meeting of Commission XIII "Fatigue Testing" of the International Institute of Welding was quite as full as that for the Opatija meeting in 1959. However, equal progress has not been made with all the various matters in which the Commission is interested.

For example, as a result of the enquiry opened in March 1954 on *fatigue failures in service*, eight documents were considered, seven of which the Commission was able at the meetings to recommend for publication. These documents describe the most

varied instances of failures, as will be seen from the following list:

Fracture of a web of a crank-shaft repaired by welding (Resolution 1)

Fracture of an intermediate shaft of a deep-sea trawler (Resolution 2)

Fracture of a roller fabricated by welding from a tube and sections (Resolution 4)

Fatigue fracture of turbines of silage machines (Resolution 5)

Fracture of a tie-rod (Resolution 6)

Fracture of a diesel engine connecting-rod (Resolution 7)

Fracture of a crank-shaft (Resolution 8).

The Governing Council approved the recommendations for the publication of these documents.

With regard to the second document, the Commission recognised that there were good grounds for extending the enquiry beyond cases involving welding in the proper sense of the word to those involving only the various allied processes such as oxygen cutting, flame heating, etc. The Governing Council approved a resolution to this effect.

The enquiry on fatigue failures is thus now progressing smoothly. In addition it is beginning to have repercussions in neighbouring fields and it is a matter of great satisfaction for the Commission to see Commission XIV "Welding Instruction" making use, for the purposes of welding education, of the documents published by Commission XIII, and to learn that Commission IX "Behaviour of metals subjected to welding" is engaged in a parallel investigation on brittle fracture.

On the other hand, it must be admitted that the investigation started last year by Commission XIII on the *frequency distributions of the stresses (or loads) in constructions in service* has so far been almost fruitless. However, judging by the precedent of the investigation on fatigue failures in service, which at the beginning was no less disappointing, the Commission does not think there is any necessity for it to be discouraged. On the contrary, the more active participation this year of certain countries, such as the United States, foreshadows valuable progress in this field in the coming year.

Among the questions dealt with by the Commission in 1959 there are others on which activity has ceased for the moment; among them are the study of the *influence of various building-up processes on fatigue strength* and the *determination of the fatigue limit using a single test piece*. This apparent torpor is largely the result of the fact that the time required for fatigue tests does not always allow of much progress being made in the space of a year. However, the Governing Council has agreed that, in response to an invitation from the American Welding Society, a paper on the second of these two subjects should be presented at the 1961 meeting of the A.W.S. and the lecturer chosen, Mr. Cazaud (France), will include in his paper both the interesting unpublished experimental results already available, and those which are achieved between now and then.

To make up to some degree for the relative absence of activity in the fields which have just been mentioned, the Commission had on its agenda various new questions. The first, emanating from Commission XV "Fundamentals of design and fabrication for welding" was a request for advice on the *method of fatigue calculation, account being taken of the instability of the variable stresses*, proposed for welded constructions by the late B. N. Ducinsky (U.S.S.R.) (Doc. XIII–227–60). Bearing in mind that the value of the theory on which the proposed method is based, could only be assessed directly by experimental evidence, the Commission noted that the most recent information available to it tended to cast doubts on the validity of the bases of the proposed theory, and even on the possibility of covering by one theory only the number of phenomena corresponding to all possible practical conditions: for example, significant damage can be caused by stress cycles of amplitude very much lower than the conventional fatigue limit when these are associated with stress cycles higher than this limit. While at present recommending caution in the application of the Ducinsky method, the Commission is nevertheless proposing to continue to study this question so as to be able to collect for Commission XV any information which would serve to define the area in which the theory could be safely applied. The Commission's views and its decision were the subject of a resolution which was approved by the Governing Council.

Commission XIII has had to consider the allocation between Commission X "Residual stresses and stress relieving" and itself of work concerning *the study of local heating and allied treatments* used to increase the fatigue strength in accordance with suggestions initially made by Puchner (Czechoslovakia) (Doc. IIW/IIS–27–59). Under the agreement reached, Commission XIII has been allotted the area defined by the following four points which appeared in a resolution approved by the Governing Council.

(1) Application of spot heating (or local compression) to weldable materials other than mild steel for the purpose of establishing the effect of this treatment on fatigue properties.

(2) Application of this treatment to joints containing load carrying welds.

(3) Application of this treatment to other forms of joints currently used in practice (for example, lattice girder connections, tubular connections).

(4) Study of methods for controlling the application of this treatment. The Commission has so far not been able to draw up a programme of work covering any of these four points because it has not full information about results already obtained in Great Britain. But as soon as it has been received, the report on these results will be studied with great interest in each country and it is to be expected that practical steps can be decided upon at the New York Assembly in 1961.

On the other hand there are two fields in which it has been possible to take effective action this year; tests on butt joints and the study of weld defects.

The report of the *comparative tests on butt welded joints* using test pieces prepared in a single works, has now been drafted in its final shape (Doc. XIII–208–59), but, before recommending its publication, the Commission thought it preferable to wait until the document can be completed by the report of analogous tests in which the test pieces will be prepared by different works. Document XIII–213–60 defines the general framework of these new tests for which the necessary steel has already been made available the detailed instructions are in course of preparation in which

seven countries have undertaken to collaborate; a rapid conclusion of this work may therefore be expected.

With regard to *weld defects*, the Commission shares the view expressed in Document XIII-219-60 "Note on the necessity for studying the influence of defects", and has recognised that it is necessary to gain by experiments, a clearer idea of the influence of these defects on the fatigue strength of welded assemblies. The programme of tests to be jointly undertaken will be drawn up by a working group in which the delegations of Belgium, France, Germany and the United Kingdom have already agreed to participate, while those of Italy, Sweden, and the United States will intimate later whether they can take part. The United Kingdom delegation has undertaken to provide all the test pieces, the techniques to be used in the preparation of defective test pieces being under development at the British Welding Research Association, and also to send all members of the Commission, for checking and completion if necessary, a review of the literature on the influence of defects on fatigue strength.

Generally speaking, Commission XIII has sufficient work in hand to allow one to hope that it will be able to carry out useful work next year at New York, in spite of the unusually short interval between the 1960 and 1961 Annual Assemblies.

Commission XIV: WELDING INSTRUCTION

(*Chairman—Mr. Almar-Naess*—Norway)

At the Annual Assembly of the IIW in Liège, 22 delegates and experts representing 14 nations attended the meetings of Commission XIV. A preliminary meeting of rapporteurs of the Commission was held in Paris on 1st February (Doc. XIV-123-60 "Report of the meeting"), to discuss new reports and to prepare the agenda for the meetings in Liège.

A considerable number of papers were submitted at the Liège meetings and discussion had to be restricted to matters still on the agenda from previous meetings and to subjects deemed of major importance in the carrying out of the Commission's work in the future.

1. Training of welders

XIV-111-59 "*Instruction sheets for welding, brazing and cutting*"

This paper was presented by Mr. Knutson-Ek (Sweden) in Opatija, but there had not been sufficient time to discuss it critically. It described a new teaching system for the elementary training of welders, based on the TWI method, which would facilitate instruction in numerous instances. Certain problems may arise in adapting the paper for international use, as welding equipment differs in design from one country to another. Mr. Knutson-Ek agreed to present a revised paper at the next meeting which would be expanded to include a comprehensive study of gas welding of steel. He invited Mr. Clack (United Kingdom) to work with him and requested observations on this subject from other members of the Commission.

XIV-114-59 "*Training course for welders*"

Mr. Goldschmidt (Belgium), in introducing this paper, emphasised that the authors were members of the Belgian delegation. The paper dealt with a three-year afternoon course of study, designed primarily for the general training of craftsman apprentices rather than as part of a scheme for the training of welders. A lively exchange of opinions followed in the discussion and delegates gave details of similar courses in other countries.

XIV-127-60 "*Training schemes for manual welding of aluminium*"

This report arises from a decision made in Opatija to ask Mr. Clack to study, from the point of view of training staff, the problem of welding aluminium and its alloys in relation to the welding of steel. Mr. Clack's contribution was confined to the gas welding of aluminium and in the discussion which followed the divergence of opinion was so great that no agreement could then be reached. Delegates agreed to give information on this subject to Mr. Clack, who will revise the paper for the next meeting and extend it to include other joining processes.

XIV-128-60 "*Training tests and marking schedules for trainee welders*"

This report by Mr. Clack is a supplement to Document IIS/IIW-44-60 (ex doc. XIV-90-58) "Training the welding technician" and describes a system for evaluating weld tests by dividing the results of the examination of a specimen into a number of different columns, so that each column can be marked independently. It was resolved to recommend the paper for publication after certain amendments had been made and this resolution was approved by the Governing Council.

2. Training of welding engineers for nuclear power projects

Document XIV-129-60, by Mr. Weddell (United Kingdom) on the training of welding engineers for nuclear power projects was discussed. It was agreed that the training of these engineers will be very necessary in view of the development of new welding techniques and materials in nuclear energy projects. Mr. Weddell was asked to obtain information from other member countries on the advanced training of these engineers and to submit a detailed report at the next meeting.

3. Books and equipment for welding instruction

XIV-125-60 "*Film strips and wall charts*"

Wall charts suitable for teaching have been discussed by the Commission on several occasions. In this paper Mr. Knutson-Ek emphasised again the great value of film strips and wall charts as teaching aids and showed examples of film strips and some small copies of wall charts used for the elementary training of welders in Sweden. A vast number of good slides, film strips, and wall charts exist at teaching centres, but the difficulty lies first, in making these known to all interested and second, in covering satisfactorily certain fields, not yet included in these teaching aids, such as welding design and various welding processes.

The problem can be approached in two ways, either by collecting information on existing material in member countries or by preparing the desired film strips and wall charts within the Commission. The

pros and cons of these solutions were dealt with in the course of a thorough discussion. It was resolved to form a working group consisting of Messrs. Knutson-Ek (Chairman), Van den Berg (Netherlands), Baggerud (Norway) and Clack, to review existing film strips on the elementary training of gas welders and to produce a new film strip incorporating the most satisfactory elements in the existing films. The group was also asked to make a similar study of the wall charts on the same subject and as there was an obvious need for film strips on arc welding, it was requested that the group should, at the same time, collect material for the preparation of these films. This resolution was approved by the Governing Council, account being taken of the necessary liaisons to be made with Commission I "Gas welding and allied processes" and Commission II "Arc welding".

Doc. XIV–131–60 "*Publications on welding instruction: Books*"

Doc. XIV–132–60 "*Publications on welding instruction: Films*"

These documents were drawn up by Mr. Puccini, Italy, as the result of a decision made by Commission XIV in 1954 to collect lists of books and pamphlets published in the various member countries and of films suitable for welding instruction and to make these lists known to interested organisations.

The first part of this work is now complete and the Commission has decided that the attention of member societies should be drawn to these documents. A resolution to this effect was transmitted to the Governing Council which subsequently approved it. Delegates were asked to send information on new subjects to Mr. Puccini who has agreed to revise the original document every other year, or when sufficient information has been received.

4. Making IIW work available to teaching bodies

Mr. Granjon (France) and Mr. Almar-Naess were asked in Opatija, in 1959, to investigate reports and documents of the IIW from the point of view of their value in welding instruction. The Commission's attention was drawn to Document IIS/IIW–30–59 (ex doc. XI–26–58) "Recommended welded connections for pressure vessels". The following resolution was transmitted to the Governing Council which subsequently approved it: "Commission XIV notes with great interest Document IIS/IIW–30–59 (ex doc. XI–26–58). It appreciates its teaching value and hopes that action will be taken by each member country to ensure a wide circulation of this document, not only to interested firms, but also to educational bodies".

IIS/IIW–37–59 "*Fatigue fracture of a longitudinal member of a lorry under frame*" and other documents

At the Opatija meetings in 1959, Commission XIII "Fatigue Testing", in a resolution submitted to the Governing Council, drew the attention of Commission XIV to the above named document because of its value in teaching. It was decided, when this document was discussed in Liège by Commission XIV, to study, from the point of view of their value in teaching, the other documents on fatigue failures in service collected since 1954 by Commission XIII and to submit to that Commission the result of preparatory work in this connection. Mr. Granjon and Mr. Almar-Naess have agreed to carry out this task and the Governing Council has approved the resolution transmitted to it on this subject.

During the discussion, the importance of finding means of applying the work of the IIW to teaching was stressed and the use of film strips was suggested as a possible method.

5. Training operators for radiographic and ultrasonic testing

Doc. XIV–130–60 "*Report on training of radiographic and ultrasonic operators*"

In this paper, Mr. Rozanic, Yugoslavia, emphasised the shortage of well trained operators, gave a general outline of his ideas for a possible training curriculum and asked for the opinions of delegates on the main points of this curriculum. A very interesting discussion followed. Mr. Rozanic was asked to continue as rapporteur and to present at the next meeting a paper on the various opinions expressed during the discussion. All the delegates were requested to complete a questionnaire, circulated by Mr. Rozanic, on training possibilities in their respective countries. Mr. Rozanic will effect the necessary liaison between Commission XIV and V "Testing, measurement and control of welds".

Commission XV: FUNDAMENTALS OF DESIGN AND FABRICATION FOR WELDING

(*Chairman—Dr. U. Guerrera*—Italy)

At the Liège meeting of Commission XV of the International Institute of Welding (IIW) delegates and experts from the following countries were present: Belgium, Czechoslovakia, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, Switzerland, United Kingdom, U.S.A., Yugoslavia, and several observers from various countries.

During the four sessions, the following subjects were discussed:

(1) selection criteria for steels for welded constructions
(2) strength of welded assemblies subject to static loading
(3) constructions in aluminium.

Since the 1959 Annual Assembly at Opatija, Subcommission A "Calculation of welded constructions subject to static loading" had held two meetings, one on 18th and 19th December, 1959 in Brussels and the other on 8th and 9th April in Düsseldorf; Subcommission B "Calculation of welded constructions subject to dynamic loading" had met once on 29th March, 1960, at Abington (United Kingdom).

1. Selection criteria for steels for welded constructions

These criteria were discussed with reference to Document XV–105–60 (IX–246–59) "Classification of structural parts" submitted by Commission IX "Behaviour of metals subjected to welding" to Commission XV, for comment. This document deals with the factors which should be taken into consideration when choosing the steel to be adopted for the components of a welded construction. These factors are the following: thickness of the plates or sections, location of the welded joints, intensity of stress,

permanent distortion due to cold forming of the components used, low service temperature and the importance of the quality of the assembly work. The Commission agreed, in principle, on the importance of these factors but, whilst retaining the document for further study by a Sub-commission, expressed the opinion that two additional factors, namely, constructional details of the component and the standard of quality required for welds, should be considered. In this document, furthermore, a scale of increasing numerical values is proposed, to the influence of each one of the above-mentioned factors. In each case, by totalling the values thus calculated the choice of the steel may be verified according to the number obtained. Indeed, the four steels under consideration in "Recommendations of the IIW for the choice and classification of steels for use in welded structures" (Document IIS/IIW-22-59, ex doc. IX-230-58) would themselves bear indices, in the form of numbers increasing with the quality, so that if the steel is well chosen, the total of the values relating to the different factors would be lower than the number characterising that particular steel.

The Commission expressed some doubt as to the validity of this method and asked Sub-commission C "Design for welding" to study the question more fully.

2. Strength of welded assemblies subjected to static loading

2.1 *Calculation formulae for welded connections subjected to static loads*

The above heading is the title of Document XV-107-60 prepared by Sub-commission A.

The contents of this document were first presented at the 1959 Opatija Assembly and have now been fully revised in the light of new tests and of further discussions within the Sub-commission. The calculation of weld seams in joints with butt straps subjected to tensile stresses or torsion and in assemblies subjected to bending or torsion at the ends of beams is dealt with in this document.

This work is based, not only on existing knowledge but also on the results of tests carried out by Commission members in order to clarify doubtful points.

When the document had been examined and discussed, the Commission passed a resolution, approved by the Governing Council, recommending the publication of this document for comment.

2.2 *Other work concerning the strength of welded assemblies subjected to static loading*

Professor Vreedenburg (Netherlands) presented the results of research on the influence of the lay-out and type of butt strap on the tensile strength of a joint with double butt strap; the butt straps in question were plates L, T and U shaped sections, etc. It was shown that when L, T and U shaped sections were set out on the components they were to join so as to give the least eccentricity at the line of action of the force passing through the sections in relation to the axis of the joint, the joint has almost the same strength as joints with cover plates; on the other hand, if the sections are placed as far away as possible from the axis of the line of action mentioned above, there may be a marked fall in the strength.

The corresponding document, XV-109-60, entitled "Static tests on welded connections with eccentrically loaded side welds" was, after examination and discussion, recommended by the Commission for publication. The Governing Council adopted this recommendation.

Professor van Douwen (Netherlands) reported on a new research project, begun in the Netherlands, on the influence of the three stresses $\sigma_{/}$, $\tau_{/}$ and $\tau_{//}$, acting separately, two at a time, or three together, on the strength of a weld seam, in order to verify the formula

$$\sigma_e = \sqrt{\sigma_{/}^2 + 1{\cdot}8\,(\tau_{/}^2 + \tau_{//}^2)}$$

which is the result of experiments carried out some years ago by the same Dutch research centre and adopted by ISO/TC 44 "Welding". From recent experiments, it seems that the influence of $\tau_{/}$ and $\tau_{//}$ on the fracture is not the same and that the coefficient 1·8 should be replaced by the coefficient 1 for $\tau_{//}^2$.

Finally, the Chairman of Sub-commission A, Professor Vreedenburg, presented an international research project on the strength of joints with butt straps subjected to tensile stresses; under this project, all the main parameters will be varied so that a confirmation of the formulae proposed in Document XV-107-60 may be obtained by large scale tests. Representatives from ten countries agreed to take part in this project, necessitating in all more than 300 test-pieces.

3. Constructions in aluminium

The Chairman of the Working Group "Design of welded constructions in aluminium and aluminium alloys", Mr. Amirikian (U.S.A.), presented a first report on general information on the use of welding in aluminium constructions in the United States. Mr. Thran, the Swedish delegate to Commission XV, presented four experimental reports, three (XV-115, 116 and 117-60) on general problems, namely, the influence of temperature changes on constructions in both steel and aluminium, the comparative behaviour of steel and aluminium alloy surfaces in relation to abrasion and the effect of abrasion on the fatigue strength of the aluminium alloys; the fourth document (XV-118-60) gives the results of comparative tensile tests on butt joints of thin sheets of Al-Mg alloy welded by the Mig and Tig processes.

The Working Group studying aluminium was asked to take these reports into consideration in its future work.

The working programme of the Group was examined and it was decided that it should deal first with Al-Mg alloys containing between 3 and 5% Mg welded by the Tig and Mig processes; the aim of the work will be the establishment of recommendations:

(*a*) on edge preparation for welding
(*b*) on the calculation of weld seams
(*c*) on the design and execution of welded constructions.

International WELDING

Training the Welding Technician

By V. W. Clack (United Kingdom)

The object of this report is to attempt to outline the basic subject matter required in a course for the training of a welding technician. Because it is considered essential for a person starting a welding technician's course to have had practical welding experience, it has been found necessary to include in the report a brief outline of some of the fundamental problems related to the requirements and duties of the welder.

The welding technician has been defined in terms of his educational capabilities, and it is proposed that the course for welding technicians should be composed of three subjects which broadly consist of: (1) *the technology of welding*, (2) *the related science and* (3) *practical welding. Under these three headings more detailed proposals are given* (see *Tables I, II and III*). *Appendix 9 contains details of a popular course for welding technicians which is available in many technical colleges in the United Kingdom.*

Some delegates on Commission XIV have given details of training schemes for the welder and the welding technician as operating in their own countries and details of these schemes are appended. When this information is complete, it may be possible for Commission XIV to put forward an approved scheme of work for the training of the welding technician.

The Welder

IDEALLY, the acquisition of any degree of welding skill in the performance of a particular task is the result of many variable factors which are usually extremely difficult to assess. Basically, as far as the welding operator (hereafter called the welder*) is concerned, it is imperative that he possess good eyesight to observe the behaviour of the weld being made, and quick reactions to correct instantly any unsatisfactory welding conditions that he observes developing. This implies good co-ordination and muscular control, factors which are prime requisites in other skills and of paramount importance for the welder. But of what use are these factors to a welder who is unable to differentiate between good and bad welding conditions, or is, in fact, unable to make a satisfactory weld? Some degree of training is obviously essential—but what kind of training?

The training that the welder receives will depend largely on the end product, *i.e.*, is the training intended to produce a fully competent welder in gas and arc welding, in all positions and on all metals and alloys? In fact, no training scheme could hope to produce such a man because depth of knowledge and experience can only come after many years of contact with practical

Report IIS/IIW-44-59 (ex doc. XIV-90-58) of Commission XIV "Welding Instruction" of the International Institute of Welding. 644

* For the purpose of this paper, a welder is a person who welds metal by a manual process as distinct from automatic or semi-automatic welding processes such as spot welding.

welding, and its problems, at workshop floor level. On the other hand, it has been found possible to train persons with no previous welding experience to perform simple routine welding operations satisfactorily, after only a few hours practice. This latter policy is only economical when the quantities of the same product are large in number. Upon completion of the order, this single purpose welder has to be retrained in another aspect of welding technique.

Courses for the training of such personnel are outside the scope of this report, but nevertheless, all welders have to satisfy, in varying degrees, the following requirements:

(1) To be prepared to work in complete isolation for extended periods in awkward and confined positions. This may involve severe physical discomfort which is increased by the heat from the welding operation, but the welder's patience and concentration must not falter in any way.
(2) To be absolutely trustworthy and of high integrity where workmanship is concerned. Unsound welds of good appearance cannot be tolerated as a 100% inspection of welded work is neither possible nor desirable. The fullest co-operation of the welder in this aspect of his work is therefore essential.

Welding is performed in British industry not only by persons whose craft is welding, but also by craftsmen in other trades—coppersmiths, sheetmetal workers, boiler makers, etc. Basically, a welder's job is to weld and it is thought by some that if a welder is called upon to do other jobs, such as edge preparation or fabrication and assembly, his time is not being efficiently spent. For example, consider the butt welding of 16 s.w.g. (1·63 mm) stainless steel sheet, the weld to be subsequently ground and polished; the operations involved consist of:

1. Tack welding
2. Dressing the tacks
3. Welding
4. Dressing
5. Grinding excess weld metal
6. Dressing
7. Final grind, scurf and polish.

Operations 1 and 3 above are definitely the welder's, operations 2, 4 and 6 above may be the welder's or, by traditional inter-trade-union agreement, they may be performed by the coppersmith or sheet-metal worker. On the other hand, operations 1, 2, 3, 4 and 6 may all be performed by the coppersmith or sheet-metal worker. It is fairly certain, however, that the polisher or metal finisher will be the only person performing operations 5 and 7!

In general, it is now common to employ welders for welding in preference to employing craftsmen in other trades who not only follow their craft, but can also weld as and when required. Important factors governing this problem are the size of the company, the degree of division of labour and the product of the company concerned. To summarise, if a company is engaged in one-off or small batch production of highly specialised fabricated components, it may be cheaper to employ craftsmen who can weld. On the other hand, if the company has a number of continuous production lines involving fabricating and welding, it would almost certainly employ, amongst others, welders.

Training Schemes

The welder

Where can a person learn to weld? Many welders in the past have been trained within industry, perhaps during their apprenticeships if they have been learning a trade in an ancillary craft. Others may have been attracted to welding and subsequently selected for a welding operators' course. Where there is a sufficient demand, a company may operate its own welding school, or the trainee welder may be placed for a week or so with the master welder of the company to pick up a few hints. This latter procedure is still very common, but not the most successful, as the best welder in the shop is not necessarily the best welding instructor.

Any training scheme for welders which relies on practical work alone cannot hope to be successful. On the other hand, no skill or craft was ever learnt from reading alone, but there are certain parts of the training of a practical welder which are far better studied in the comparative calm of the lecture room. Of the many schemes for training welders in the United Kingdom, it would seem that 90–95% of the course time is spent in actual welding practice, whilst the remainder is spent in the lecture room.

Very popular courses for training the welder are those offered by manufacturers of welding equipment. The duration of these courses varies slightly, an average course being of three weeks. Fuller details of some of the schemes operating in the United Kingdom are to be the subject of a further report.

These schemes are works based, that is, they are not organised by educational authorities, but are offered in the welding schools organised and administered by the various companies vitally interested in welding.

The welding technician

To be a technician in any branch of engineering implies:

(1) a thorough knowledge at workshop floor level of the practice of the particular branch
(2) a good understanding of the matter related to the science and technology of the subject
(3) a fair understanding of the directly associated practices.

In other words, the technician is a person who not only knows 'how', but has some knowledge of 'why' certain phenomena take place. It is impossible to establish absolutely at what stage the welder, for example, becomes a welding technician, or when the latter in turn becomes a welding technologist or engineer (if ever), but here again we have fairly well established yardsticks to guide us.

The welder may be assessed by his ability to make welds in accordance with a particular code or standard. The welding technician will, in all probability, have satisfied, at some stage in his progress, the tests for a welder. In addition, he will have studied a limited amount of the science and technology associated with welding, for example, under the heading of Science, the subjects of Properties and Strength of Materials, Electricity, Heat, Metallurgy, etc., whilst for Technology the relation of the sciences to basic techniques and universal practices would be an important requirement. For the welding engineer, a professional qualification in a branch of engineering or metallurgy

Table I

WELDING TECHNOLOGY

The Processes

Safety

Electric	**Gas**
Plant & Equipment	Fuel Gas & Plant
Inert Gas Welding	Blow-pipe & Flames
Electrodes	Oxy-Cutting & Gouging
Resistance Welding	Brazing
Weldability	Filler Rods

Ancillary Equipment
Techniques & Procedures
Edge Preparation
Distortion & Residual Stresses
Testing & Inspection
Hard Facing
Workshop Layout
Jigs & Manipulators
Design
Joint Strengths
Costing

is considered by some to be essential, in addition to a good knowledge of some branch of welding. To sum up, we shall regard the welding technician as one possessing a superior theoretical knowledge to that of a welder, but educationally inferior to a welding engineer.

What requirements must the welder fulfil before embarking on a course which aims to produce welding technicians?

(1) He should be a skilled welder and show above average knowledge in his work as regards job layout, electrode selection, conditions conducive to good welding, etc. He should be able to communicate his ideas and thoughts not only to his juniors but to those senior to him as well. Personal keenness and ambition are also very important requirements.

Ideally, the welder satisfying these conditions might be released for a portion of each week without loss of income in order to pursue his studies. This involves the co-operation and goodwill of both the management and the employee. On the other hand, it may be possible for the welder to study in his own free time, but here there are many extraneous factors to consider, such as the location of the course in relation to his home or work or both, home environment, fatigue, etc. No hard and fast rules can be laid down, except that it is considered that close liaison between the employer and trainee welding technician is essential, irrespective of when or where the course is pursued.

(2) He should be at least sixteen years of age, and have received a good general education. He must be able to comprehend what he reads, and be able to write a reasonable account of a particular job or procedure with which he has been intimately connected. Simple calculations should be well within his scope, along with an ability to understand a workshop drawing. Apart from these requirements, the broader his general knowledge is, the better.

(3) He should be likely to profit from attendance at the course. If he is not interested in the course he may well be keeping away another who is interested. This is probably the most difficult of all the entry requirements for the college authorities to solve satisfactorily. In fact, a student who gives up his own free time to attend the course is likely to be more determined to succeed than one who gets time off from work to do so. It would seem that a combination of spare time plus the employer's time for study might provide a satisfactory compromise.

Mention has already been made of the basic subjects for a course which aims to produce a welding technician, namely Technology and Science. Subject headings of the work relating to Technology and Science are given in Tables I and II.

Experience has shown that the teaching of the technology of welding is well received by the welding student, as it is very closely related to actual welding operations and deals generally with terms and equipment with which he is probably familiar. On the other hand, the related science and metallurgy syllabus presents a serious problem, and it will be found necessary to have continually in mind the fact that we are aiming to produce a technician and not a technologist. Particularly in the teaching of these subjects, it is vital to explain in the simplest possible fashion some of the fundamental phenomena that are involved when a weld is made. It will require considerable skill on the part of the teacher to keep to the study of science and metallurgy related to welding without going too deeply into the subject, and yet to use terms which the student can understand. To simplify the subject without resorting to inaccurate statements is difficult but essential.

Table II

WELDING SCIENCE

Heat	**Mechanics**	**Chemistry**	**Electricity**
Temperature & Heat	Stress & Strain	Elements, Atoms, Molecules	Electrical Energy
Expansion & Contraction	Elasticity & Plasticity	Oxidation & Reduction	Plant & Equipment
Three States of Matter	Temperature Stresses	Solubility	Arc Characteristics
Heat Quantitites	Distortion & Residual	Saturation	
Properties of Gases	Stresses	Precipitation	
		Alloys, Fluxes, Gas Flames	
		Oxygen Cutting	

Metallurgy
Types of Steel
Cooling Curves
Alloy Steels
Temperature Effect on Structure
Hardening & Annealing
Overheating
Gas Effects on Liquid Metals
Heat-Affected Zone
Weld Structure
Hot & Cold Work
Surface Hardening
Copper & its Alloys
Aluminium & its Alloys
Macro & Micro Examination

A person claiming to be a welding technician must be able to weld. Here again, experience has shown that practical welding should be integrated in the course. It all too rarely happens that an excellent welder starts to

Table III

Minimum practical requirements for a welding technician

Gas welding—He should be capable of making:
- (*a*) Butt welds in the downhand position in mild steel of thicknesses from 0·048 in. to 0·25 in. (1·22 mm to 6·35 mm)
- (*b*) Butt welds in copper, brass, aluminium, stainless steel and cast iron
- (*c*) Welds between bars and pipes of up to 2 in. (50 mm) diameter
- (*d*) Fillet welds.

Arc welding—He should be capable of making:
- (*a*) Butt welds in the down hand position in mild steel thicknesses from 0·048 in. to 0·25 in. (1·22 mm to 6·35 mm)
- (*b*) Butt welds in aluminium, stainless steel and cast iron
- (*c*) Welds between bars and pipes of up to 2 in. (50 mm) diameter
- (*d*) Fillet welds.

In order to assess the merits of the welding, the following tests are to be used where appropriate: visual examination; plain bend; reverse bend; macro examination; and nick break.

train to be a welding technician, and therefore it is necessary to insist not only on course work or specimen work, but preferably also on some form of practical welding examination. The level of this practical examination will depend on ability at entry, duration of the course, national standards and so on. But it is thought that the minimum practical requirements which a welding technician should fulfil in order to qualify are as given in Table III. If an applicant for the course can fulfil these minimum requirements at the time of his entry, then he should be given more advanced or varied work or both during the practical lessons.

Within the framework laid out in Tables I, II and III most schemes for training the welding technician may be accommodated, and particulars of those operating in various countries are given as Appendixes to this report. When this information is complete, it is hoped that it may be possible for Commission XIV to put forward an approved syllabus for a welding technicians' course.

It will be seen from the study of the Appendixes that in only a few member countries are courses available for the training of the welding technician. In these countries, the general pattern of the courses, *i.e.*, subjects studied, duration, standard, etc., are approximately the same. Entry qualifications for such courses vary considerably. In the United Kingdom, emphasis is on practical workshop welding experience, supplemented by part-time day or evening study at a local technical college. In France, it will be noted that one of the courses requires three years full-time study starting at the age of fifteen years, it being unusual for the applicant to have had industrial experience. This is fundamentally different from the United Kingdom concept of courses intended to supplement the industrial experience of the craftsman. It is this factor on which the largest divergence of opinion is found. In practice, there is evidence to suggest that the persons trained by either scheme are eagerly sought after by industry, and ultimately there is little to choose between the products of each scheme.

The subject matter for the courses appears to be adequately covered by Tables I, II and III, although here again, the technology syllabus would have to be dealt with in more detail when the students have little or no industrial experience. On the other hand if, for example, physics has been studied by the student before embarking on a course to train him to be a welding technician, some of the contents of Table II might be omitted. These are points of detail upon which, because of traditional procedures obtaining in member countries, we are unlikely to secure universal agreement.

It is felt, however, that the proposals contained in the paper are broad enough to meet the approval of all, though they should be regarded as minimum requirements only. In this connection it may be of interest to record that the United Kingdom scheme given in Appendix 9 has, within the last few months, been superseded by a more comprehensive scheme requiring at least one further year of study, with practical welding tests in positions other than downhand. Thus the United Kingdom are demanding more than the requirements specified in Table III for a Welding Technician.

Acknowledgments

The author wishes to express his thanks to Dr. S. C. Robinson, Principal of Wandsworth Technical College, London, for permission to write this paper, and to the City and Guilds of London Institute for the information contained in Appendix 9.

APPENDIX 1—Belgium

The information received from Belgium was contained in a paper by J. Elaerts called "Professional Education of the Welding Technician" and it was not clear whether or not the information contained therein related to schemes that were in fact in operation at the present time. The paper contained information regarding the pre-entry requirements to the Welding Technician course proper. These consisted of a three or four year course of thirty weeks duration with approximately ten hours study per week. The subjects studied are welding technology, welding practice and the design and preparation of welded work. Thus, at the age of 21 or 22 years, a person having successfully completed this course would be suitable for the higher level training of a welding technician.

In this more advanced study of welding, the amount of practical work would be limited, the aim being not

Programme 1

Curriculum	
Terminology—signs—conventions	4 lectures
Electric arc welding	24 ,,
Resistance welding	5 ,,
Atomic hydrogen	3 ,,
Gas welding	24 ,,
Preparation	3 ,,
Brazing and bronze welding	5 ,,
Gas cutting	10 ,,
Application of oxyacetylene welding	6 ,,
The metallurgy of welding	8 ,,
Weldability	12 ,,
Distortion and residual stress	10 ,,
The economics of welded work	5 ,,
Limitations of the various welding processes	3 ,,
Industrial application	12 ,,
	134 lectures

Programme 2 (*specialised*)

	Group A (*Design*)	*Group B* (*Workshop*)
Design of welded structures	10 lectures	—
Mechanical testing of welds	—	5 lectures
Safety regulations	—	4 ,,
Welding shop organisation	—	6 ,,
Laboratory periods	10 lectures	20 ,,
Administrative	80 ,,	15 ,,
Practical welding	30 ,,	80 ,,
	130 lectures	130 lectures

to produce manual perfection, but to show variations of well-established practices and to demonstrate good and bad welding procedures. Details of this course are given in Programme 1.

More specialised welding courses requiring two years of part-time study are also indicated. Such courses extend over thirty weeks per year with study periods of eight hours per week. It is recommended that the instructors be welding engineers. Details of two such courses are given in Programme 2.

APPENDIX 2—Czechoslovakia

The contribution from Czechoslovakia was as follows:

The Training of Welding Technicians

The Welding Technicians are to be the leaders of the individual welding groups in the works. They should be selected from the ranks of the universal welders after they have had at least ten years industrial experience and have also attended a three months' full-time welding course in the works welding school or research institution.

The training scheme would, in principle, be similar to that for a "universal welder" with the difference that the syllabus would be more profound and specific. The progress of the welding technician should be guided by the welding engineer.

APPENDIX 3—Denmark

A course for training the welding technician is in operation throughout Denmark. It is of short duration but may be extended in special cases, and is available as either a day or evening course. The syllabus is as follows:

Hours	Instruction
3	Operation and performance of arc welding plant
3	Exercises in "string beads"
1½	Electrodes—types and uses
1½	Exercises in weave beads
3	Exercises in making fillet welds
3	Exercises in making fillet welds by overlapping
3	Demonstration of welding V butt weld
3	Bending tests with evaluation of faults
6	Exercise in making V butt weld, open root
3	Demonstration and exercises—vertical welding
3	Demonstration and exercises—horizontal on vertical
3	Demonstration and exercises—overhead
9	Demonstration and exercises—pipe welding

45 hours plus 15 hours of lectures.

APPENDIX 4—France

The instruction given at the Institute of Welding in Paris is at various levels, of which some, concerning the training of technicians, are mentioned below. Thanks to grants from industry of welding materials, and to state grants in the form of the "Apprenticeship Tax", some of the courses are given either *gratis* or at much reduced fees. It will be recalled that the Institute of Welding trains welding engineers (Senior School of Autogenous Welding—E.S.S.A.), and that it gives courses of practical training to beginners or qualified welders (beginners' course and finishing course).

The instructional activities that particularly concern technicians are the following:

(1) The Professional School of Welding receives, full-time for three scholastic years, pupils aged from 14 to 16 years in the first year, who have just left a state school. They are trained by various methods, in the theory and techniques of welding, and receive a general training at the same time. They are also initiated into metal-working techniques, such as fitting and boiler-making. The conditions of entry into the School require no industrial experience.

The weekly programme of studies is as follows:

	Time allocated, hr		
Subject	*1st Year*	*2nd Year*	*3rd Year*
Physics	2		
Chemistry	1		
Electricity		1½	1½
Mechanics		1½	1½
Metallurgy		1	1
Arithmetic	2		
Algebra	2	2	2
Geometry	2	2	2
Drawing		2	4
History and Geography	1		
French	2	2	2
Workshop Technology	2	2	2
Welding Technology	2	2	2½
Drawing and design	6	4	3
Fitting	10		
Boilermaking, Sheet Metal Work, Coppersmithing		10	8½
Welding	8	10	10
Physical Training	3½	3½	3½
Total	43½	43½	43½

Besides the Former Pupils' Certificate which they receive at the end of their course, the students are entered, usually with success, for the Professional Welder's Aptitude Certificate, and possibly for the Boiler-maker's as well. Former students of the Professional School generally occupy, after a few years' experience of welding, the post of technician, where they are much appreciated.

(2) To allow welders from industry to perfect their skill, and to acquire a supplementary qualification, the Institute of Welding organises part-time courses for them which take place on the evenings of working days in preparation for the Professional Aptitude Certificate (C.A.P.), and on Saturday and Sunday mornings in preparation for the Professional Brevet (B.P.). The first of these courses lasts for three years, the second for two.

(3) Every year, the Institute of Welding organises Sunday morning courses; these consist on the one hand of welding methods courses intended for welders from industry, and on the other of welding construc-

tion courses intended for technicians and draughtsmen from industry.

(4) Periodically, engineers and technicians from industry can follow technical and practical courses lasting a fortnight, devoted to welding methods and to problems posed by the application of welding to various sorts of construction.

These various regular courses of instruction are given in Paris; but courses are also organised in the provinces by the Institute of Welding with the collaboration of the local industries or educational bodies.

APPENDIX 5—Germany

In the German Standard DIN 4100 "Welded Steel Construction", provision is made for the certification of selected small and medium size works where construction of simple welded elements is undertaken. The certification permits the workshops concerned to construct simple welded supports, girders and other weldments which are to be subjected to mainly static loads. The sheet quality and limiting thicknesses are also specified in the standard.

The work manufactured under this certification must be welded under the constant supervision of a responsible Schweissfachmann (Welding Technician). Such personnel follow a special course of welding instruction which is the responsibility of the Research Institutes and the Welders' School of the Deutscher Verband für Schweisstechnik (German Welding Society). Only approved foremen engaged in metal fabrication and others with equal knowledge may be admitted to the course. All participants must be capable welders and have satisfied a practical welding examination defined in standard DIN 4100.

The course is of 88 hours duration and consists of lectures, demonstrations and practical training in the laboratory and workshop. In order to qualify as a Schweissfachmann, those attending the course must satisfy a written and oral examination related to the subjects studied. The syllabus, which is given in DIN 4100, is as follows:

(1) *Knowledge of materials*

Types of steel, dangerous and favourable elements, ability to be welded and forged, rolling defects and their effects, behaviour of steel at cold and warm temperatures and after cold forming, mechanical characteristics, testing processes, types of welding rods and their qualities.

(2) *Theoretical mechanics*

Flow of inner stresses, influence of cross section alterations, notches, shrinkage strains caused by welding heat.

(3) *Statics*

General knowledge and basic concept of allowable stresses (without their calculation).

(4) *Steel work construction*

Basic principles of steel work construction, reading of the welding schedule, marking and assembly in workshop and on building sites.

(5) *Welding processes*

Usual welding processes, necessary equipment, machines, auxiliary devices and their application, operation and maintenace of usual machines and equipment. Application of the different welding rods according to steel type and weld position, types of current, voltage and amperage for different welding electrodes, arc blow.

(6) *Applications of welding in steel work construction*

Forms and types of welds, preparation and assembling of elements to be welded, machining of welds according to stress type; how to reduce shrinkage strains, welding sequence, direction of welding, weld structure, atmospheric influences.

(7) *Testing of welded joints*

Critical examination of welds according to exterior appearance, destructive and non-destructive testing, their possibilities of application and their usefulness, perceptibility of defects. Necessary and possible steps towards removal and diminution of weld defects.

(8) *Regulations*

Welding regulation DIN 4100, chapters "Calculation of Welded Joints" and "Allowable Weld Stresses": Knowledge of the main principles and the important requirements for an understanding of the welding schedule. Technical specifications for welding electrodes DIN 1913, as far as they are important for the use of the electrodes.

Safety regulations.

(9) *Special literature*

Important publications on welding progress.

APPENDIX 6—New Zealand

A four year part-time course in welding is available under the "Controlling Authority for N.Z. Certificates in Engineering". The aim of this scheme is to produce welding technicians capable of assisting or relieving professional engineers of various duties, *i.e.*, inspection, overseeing, testing, etc. The first two years of the course is common to all other trades and consists of mathematics, engineering science, technical drawing and English, specialisation occurring in the third and fourth years. The subjects studied in the third year of the course are:

Strength of materials and applied mechanics
Metallurgy I
Welding technology I

In the fourth year, the subjects are:

Metallurgy II
Welding technology II
Supervision and testing.

In both years, 2 hours per week are spent on each subject.

The syllabuses are as follows:

Strength of materials and applied mechanics

Forces in equilibrium; triangle and polygon of forces; Bow's notation—simple frame structures, determination of stress in members.

Linear motion, Newton's laws; momentum and impulse. Moment of intertia; kinetic energy of rotation; centrifugal force, torque; angular acceleration.

Coefficient of friction, angle of friction, static and kinetic friction, applications to frictional devices such as clutches, belts. Simple calculations involving torque, power absorbed due to friction in journal bearings.

Lubrication and viscosity—elementary treatment only.

Rolling, air and gradient resistances; propulsive forces required; tractive effort for different road surfaces and different speeds.

Work and power, relationship between mechanical, electrical and heat units; energy dissipation in brakes. Work done and power used in overcoming rolling, gradient and air resistance at given speeds.

Stress, strain, Hooke's law; ultimate strength, factor of safety; torsion in solid and hollow shafts, bending moments, stress produced in a beam by straining actions of external forces (simple treatment only).

Metallurgy I

This course is designed to give a reasonable knowledge of the causes of trouble in the working of metals, and their eradication, and to enable students to distinguish between a defect in a metal and a defective method of treating or working it. It should be clearly understood that anything in the syllabus which covers the smelting of ores or manufacture of metals is included solely with the object of enabling the student to appreciate how certain defects or qualities are possessed by metals through the process of manufacture.

The following items should be dealt with in connection with iron, steel, and non-ferrous metals:

Physical properties in relation to their usefulness, crystal structure.
Mechanical and metallurgical operations which affect crystal size, relation between structure and properties of metals.
Heat treatment—pyrometers and their uses, hardening and tempering, case hardening, annealing and normalising.
Testing of metal in tension and compression and for hardness.
Causes of corrosion and erosion of metals, general methods of prevention or immunisation.

I. Iron and steel manufacture
(*a*) The blast furnace. Treatment and extraction of ores
(*b*) Cast iron—cupola, crucible and air furnace. Types and properties of cast iron
(*c*) Steel—Bessemer, open-hearth, crucible, arc and h.f. furnaces
(*d*) Alloy additions to steel. Properties and uses, special reference to low alloy high tensile, and other types of steel, *e.g.*, H.S.S.
(*e*) Rolling, forging and extrusion of steel.

II. Non-ferrous metals and alloys
(*a*) Treatment and extraction of chief ores
(*b*) Properties and compositions of typical brasses, bronzes, anti-friction alloys, zinc base alloys and aluminium alloys.

III. General metallurgy
(*a*) Hot and cold working of metals. Effect on properties
(*b*) Heat treatment of metals, with special reference to steels. Hardening, case-hardening, tempering, annealing, normalising. Types of pyrometers.
(*c*) Tensile, impact, fatigue and hardness testing. Root and face bends. Interpretation of results. Etchants and specimen preparation procedures
(*d*) Corrosion of metals. Method of prevention (choice of alloy and surface treatment)
(*e*) Soldering, brazing and welding. Relative effects and reasons for method used.

Welding technology I

Fundamental principles of the following processes:

(*a*) Arc welding and its variations
(*b*) Oxy-fuelgas welding and its variations
(*c*) Thermal cutting
(*d*) Thermit welding
(*e*) Resistance welding
(*f*) Fire welding
(*g*) Under-water cutting and welding
(*h*) Surfacing materials in manufacture and maintenance.

Description of equipment used in all the above processes.

Safety precautions necessary for all types of welding processes and equipment (including confined space work).

Application of fundamental gas laws to welding. Simple treatment.

Types and sources of supply of all consumable materials used in the above processes.

Types of joint preparation and reasons for same as used in all the above processes.

Welding symbols in use. Relevant standards.

Laboratory work of not less than 40 hours required.

Welding technology I and II—Laboratory work

Not less than 40 hours during each year.

Oxyacetylene
Lighting up and closing down of equipment
Safety precautions
Cutting of mild steel, alloy steels, powder cutting applications
Simple butt and fillet welds in mild steel. Position welding
Butt welds in cast iron
Simple bronze welding and brazing and hard facing.

Electric welding
Simple butt and fillet welds on mild steel in downhand, horizontal–vertical, vertical and overhead positions
Shop bend and nickel bend tests on butt welds in mild steel
Preparation of bend and tensile tests
Preparation of joints for butt welds and fillet welds in mild steel by means of oxyacetylene cutting equipment.

Resistance welding
Simple flash butt, upset butt and spot welding.
Note: Correct equipment handling procedures are to be stressed at all times.

Welding technology II
Welding symbols. Various standards, interpretation and differences
Distortion and shrinkage control
Stress flow through welded connections. Effects of finish of welded joints, filling of weld craters and fillets returned around ends of joints. Use of coupons for butt welds
Butt welds joining plates of dissimilar thickness and/or materials
Inert gas shielded arc, submerged arc, automatic and semi-automatic welding
Techniques necessary for X-ray quality welding
Estimating welded components
Quantity surveying for welded construction
Shop control of costs and quality
Field control of costs and quality
Standard specification. Laboratory work of not less than 40 hours required.

Metallurgy II

Weldability of various metals in all common welding processes.

Effect of manufacturing techniques on weldability. Various types of electrode coatings or fluxes and their effect on deposited metal. Their suitability for different power sources, positions and types of weld joints. Effect of various welding and shielding gases on molten metal during arc and gas welding.

Notch ductile steel plates for low temperature conditions (*see* BS.Draft CV (1 SE) 144). Study of the steel and its behaviour during welding.

Macro- and microscopic examination of mild steel parent metal, weld metal and heat-affected zone.

Clad sheets for special purposes.

All aluminium and aluminium alloys. Methods of manufacture and behaviour during welding with all welding processes. Heat treatments necessary. Various types of fluxes used and their effect on deposit metal. Their suitability for different alloys, position and types of weld. Inert gas shielded welding without flux.

Copper, nickel and principal alloys. Theory of chemical reaction in welding. Its effect on various metals. Effect of various gases on molten metals during arc and gas welding.

Heat treatment of welds. Preheating and post heating. Interpass temperature control. Effect of single and multi-run welds in light and heavy mild steel sections. Heat treatment of ferrous and non-ferrous metals to obtain optimum results.

Cold working, work hardening and annealing.

Supervision and testing

Supervision

Specification N.Z.S.S. 487
Routine tests of electrodes, machines, operators and techniques
Recording of tests.
Checking of dimensions and allowances for shrinkage
Method of carrying out changes of welding techniques during progress of job
Reports
Duties of welding foreman and welding inspector.

Testing

All weld metal tests of electrodes (BS.639–1952)
Welding operator tests on butt and fillet welds
Tests on site to prove equipment and techniques
Routine tests of electrodes
Bend and tensile tests in all positions (N.Z.S.S. 487)
Impact test Izod and Charpy
Hardness tests
X-ray and radio isotopes. Reading and interpretation of results
Macro and micro specimens
Pressure testing of containers.

Design principles

Simple treatment of riveted and welded joints, comparisons under axial and eccentric loads. Simple built up beams, columns, trusses and bridges. Computations for weld sizes in various positions for all types of weld. Importance of balancing welds around neutral axis.

APPENDIX 7—Norway

In Norway, there is no specialised training of welding technicians. The technical colleges in Norway have two years technicians' courses in different branches of engineering, including mechanical engineering, electrical engineering, chemical engineering, etc. Before being admitted to one of these courses, the student must have passed a secondary school course and must also have had at least 2½–3 years' practical experience as a metalwork mechanic, electrician or a chemical laboratory assistant. The age of entry will, therefore, seldom be below 21 years. The welding instruction programmes vary for the different colleges, but they all have welding theory and demonstrations incorporated in the subject of Workshop Technology. A typical syllabus is as follows:

Welding theory incorporated in the subject "Workshop Technology"

For the students at the mechanical engineering, motor engineering, naval architecture and electrical engineering departments, the following pressure welding and fusion welding processes are described: Forge welding, water gas welding, resistance welding, thermit welding, oxyacetylene welding, metallic arc welding, submerged-arc welding, atomic hydrogen welding, etc.

Students at the first three above-mentioned departments are introduced to the Norwegian Standard No. 470 which defines how to calculate the strength of welded constructions. A few calculation exercises are carried out.

The programme also includes demonstrations of arc welding equipment, but does not comprise practical work.

Duration of instruction: 25 hours.

Instruction in welding is also given to the students at the civil engineering department, but on a less comprehensive scale.

Duration of instruction: 15 hours.

Most persons entering positions of welding technicians in Norwegian industry have passed a mechanical engineering course at one of these colleges and have had previous industrial experience in metal working and welding. After some years of satisfactory work, their employers may permit them to use the title of welding engineer. This does not mean that they have proceeded to a higher level position; it is only a question of titles.

APPENDIX 8—Sweden

No special training of welding technicians exists in Sweden.

APPENDIX 9—United Kingdom

A college based course of welding instruction.

A scheme of training meant primarily for the craftsman welder is available in approximately 150 technical colleges in the United Kingdom. The scheme which has been universally adopted is intended to supplement the industrial experience of the craftsman welder by:

(1) Instruction in the science and technology of welding;
(2) Introducing him to a wider range of practice and problems than normally met in the course of daily work.

The duration of the course is three years, and consists of a minimum of 150 hours study in each year of the course. The 150 hours are spread over some 25

weeks so that at least 6 hours study per week is necessary. Local circumstances decide whether the 6 hours should occupy one day per week or be spread over three evening lectures each of 2 hours duration.

A typical curriculum is as follows:

1st Year	Practical welding (Electric arc and oxyacetylene welding)
	Welding Science
	Welding Technology (E/A and O/A)
2nd Year	Practical welding (E/A *or* O/A)
	Welding Science
	Welding Technology (E/A *or* O/A)
3rd Year	Practical welding (E/A *or* O/A)
	Welding Science
	Welding Technology (E/A *or* O/A)

It will be seen from the above that students may at second year level study either electric-arc or oxy-acetylene welding, *but* eventually to qualify in both branches additional attendance at the appropriate lectures in both the second and third year is required.

At the end of the third year the student may sit an examination which is conducted by an external body. The examination consists of:

A. A written paper of three hours duration on Welding Science.
B. A written paper of three hours duration on Welding Technology in oxyacetylene or electric arc welding or both.
C. A practical test of three hours duration in oxyacetylene or electric arc welding or both.
D. An examination of specimen work previously prepared by the candidate using oxyacetylene or electric arc welding or both.

Separate certificates are awarded to successful candidates in either oxyacetylene or electric arc welding as applicable, but it will be noted that the Welding Science examination paper is common to both branches of the subject. Further, candidates must satisfy, in the same year, all the examination requirements *A* to *D* listed above in order to qualify.

To meet the practical requirements of the course, colleges offering this scheme must possess certain workshop equipment; recommendations in this connection are given later.

Syllabuses

Electric-arc Welding Technology

General note. Teachers should refer where appropriate to the relevant British Standard.

First year

1. *General introduction*

Brief history of welding. Comparison of fusion and non-fusion welding processes with other methods of joining metals. Definitions and symbols should, if possible, refer to British Standard Specification 499.

2. *Electrical aspects* (simple treatment only)

(*a*) Direct electric current; e.m.f.; the volt; conductors and insulators; current flow; the ampere; Ohm's law; resistance; p.d. and voltage drop. Power; the watt; kW and Kw.hr. H.P. Simple treatment of alternating currents.

(*b*) Conductors and insulators, as applied to welding (cables, electrode, holders, etc.). Heating effect of the current carrying capacity of cables; fuses; resistors; contact resistance.

(*c*) Magnetic effect of the current; electro-magnetic induction.

(*d*) The electric arc and its function in welding; simple circuit for both d.c. and a.c. operation; voltage drop in the arc; regulating resistances and reactors.

ELECTRIC-ARC AND OXYACETYLENE WELDING

3. *Welding tools, etc.*

Description of electrode holders, screens and filters, tool and protective equipment in general.

4. *Electrodes*

Use of bare wire and of covered electrodes, types of coating and mode of application. Classification of electrodes. Defects in electrodes. Effect of storage conditions.

5. *Safety measures*

Leakage current, effect of moisture; earthing and safety precautions. Protective equipment; Ministry of Labour and National Service Memorandum on Electric-arc Welding (Form 329/1945 Rev. 1951).

6. *Technique*

Methods of making return lead and earth connections to workpiece. Striking the arc. Deposition of beads. Weaving. Effect of variations in electric supply voltage. Effect of current and arc length. Control of metal flow. Avoidance of slag inclusions and incomplete inter-run penetration. Control of depth of penetration. Removal of slag and spatter. Preparation and types of joints (BS). Length of weld run per electrode. Effect of welding speed and volume of metal deposited in relation to the mass and shape of work. Effect of weather conditions during welding. Effect of electrode angle.

Current values; open circuit and welding voltages.

7. *Weld defects*

General defects of arc welds; blow-holes and porosity, various forms of incomplete penetration; under-cutting; weld craters; slag inclusions. Arc-blow as a cause of defects. Causes, effects and remedies. Refer to BS.1295, factors 1 to 8.

Second year

7. *Techniques*

Preheating and post-heating. Position welds. Use of backing bars and backing strips. Welding sequence and distortion control. Arc blow and means of minimising its occurrence. Use of deep penetration.

9. *Electrical aspects*

Electro-magnetic induction and its application; the simple alternator and d.c. generator; action of the commutator; principle of the choke (reactor) and of the transformer. Simple description of three-phase supply.

10. *Weldability*

Factors affecting weldability. Weldability tests. Welding of mild, medium and high-carbon steels; cold

and hot rolled steels; galvanised iron; grey and malleable cast iron.

11. *Plant*
Simple circuits for welding plants, a.c. welding transformers and regulators; output characteristics and kVA ratings; d.c. welding generators; regulating resistances; output characteristics and kW ratings. Connections of welding equipment to main supply. Use and connections of multi-operator sets.

12. *Resistance welding processes*
Description of spot, seam, projection, butt and flash-butt, and stud welding processes. Method of heat generation by electrical resistance of metals at the contact faces; influence of current; pressure and time factors; cooling of electrodes. Manual control of time and pressure. Simple description of automatic control.

13. *Layout of workshop for arc welding*
General layout for electric welding. Types of benches, preheating appliances, facilities for handling and preparation of work, jigs and manipulators. Degreasing equipment. Typical electric and compressed air services, electrode storage cabinets.

14. *Safety*
Further study of form 329. Precautions to be taken in the welding of tanks, etc., which have contained materials likely to give rise to inflammable or poisonous gases or vapours (Form 814).

Third year

15. *Welding and cutting processes*
Fundamental principles, fields of application, and advantages and disadvantages of manual, metal-arc, carbon-arc (single and twin carbons) argonarc and atomic-hydrogen welding processes. Semi-automatic submerged-arc welding. Firecracker welding. Principal systems of automatic covered electrode, submerged-arc, carbon-arc and inert-gas shielded arc welding processes.
Cutting with the carbon-arc, metal-arc, metal-arc and the oxygen-arc processes. Use of wet covered electrodes. Hole piercing. Current densities employed. Cutting techniques.

16. *Costing. Simple treatment*
Factors influencing costs; consumption of electricity, electrodes and fluxes, rates of deposition and welding speeds. Cost of labour, plate preparation, assembly, welding time. Overheads.

17. *Weldability*
Welding tool steels, low alloy high tensile steels, stainless and heat-resisting steels, high manganese steels. Copper, nickel and aluminium and their principal alloys.

18. *The electric arc*
Characteristics of the arc. Use of consumable and non-consumable electrodes.

19. *Plant*
Simple description of various types of rectifier equipment for welding.

20. *Materials*
Use of non-ferrous electrodes. Granular and powder type, fluxes. Electrodes for metal cutting. Filler rods and metal powders for surfacing. Carbon and tungsten electrodes.

21. *Technique*
Surfacing of metals for wear, abrasion and corrosion resistance. Buttering. Spatter and means of minimising its harmful effects. Principles involved in the joining of dissimilar metals. Use of d.c. and a.c. welding for specific metals and applications. Jigs and manipulators.

22. *Testing*
Tensile, bend and impact testing. Shear and tearing tests. Brief reference should also be made to other methods of testing including non-destructive tests, magnetic crack detection, X-ray, gamma ray, ultrasonic acoustics, metallographic methods. (Reference should be made to "*Training and Testing of Welders*", BS.1295.)
Pressure testing. Testing of containers with liquids and gases. Safety precautions to be taken before, during and after testing.

Arc Welding—Scheme of Practical Work

Note.—Preparation and types of joints to be in accordance with the relevant British Standard. Particular attention to be given to distortion control. Occasional joints to be examined as defined in BS.1295. Mild steel parent metal only to be used during the first and second years.

First year

1. General description of welding and associated workshop equipment with emphasis on the safety precautions to be observed in its use.
2. Setting up and operation of both a.c. and d.c. equipment; striking the arc; angle of electrode; control of arc length; current adjustment.
3. Deposition of straight runs in the downhand position using bare wire and covered electrodes (*a*) without weaving, (*b*) with weaving.
4. Methods of stopping and restarting for continuous runs of weld deposit.
5. Slag control.
6. Over-lapped and superimposed runs in the downhand position; pad building.
7. Deposition of fillet welds of specific size, in the tilted position.
8. Tilted fillet tee and lap joints in plate $\frac{1}{4}$–$\frac{3}{8}$ in. (6·35–9·53 mm) thick in the downhand position.
9. Downhand horizontal–vertical fillet tee and lap joints in plate $\frac{1}{4}$–$\frac{3}{8}$ in. (6·35–9·53 mm) thick (one leg vertical in the case of fillet joints).
10. Close and open square butt welds in plate up to $\frac{1}{4}$ in. (6·35 mm) thick.
11. Single and double V butt joints in various thicknesses of plate.
12. Double V butt joints in rounds up to 1 in. (25·4 mm) dia.
13. Corner joints in plates of various thicknesses in the downhand position.
14. Seal runs and sealing welds.

Second year

15. Deposition of straight runs in the vertical position (*a*) without weaving, (*b*) with weaving.

16. Over-lapped and superimposed runs in the vertical position using upward and downward welding; methods of stopping and restarting for continuous runs; pad building.

17. Fillet tee and lap joints in the vertical position using upward and downward welding.

18. Open square butt joints in the vertical position using upward and downward welding in plates of various thicknesses.

19. Single and double V butt joints in the vertical position using upward welding in plates of various thicknesses.

20. Inside and outside corner joints in the vertical position in plates of various thicknesses.

21. Double V and open square butt welds in rounds of up to 2 in. (51 mm) dia.

22. Use of run-on and run-off plates.

23. Plug and slot welds in plate of various thicknesses.

24. Deposition of straight runs in the overhead position (*a*) without weaving, (*b*) with weaving, over-lapped and superimposed.

25. Fillet tee and lap joints in the overhead position.

26. Butt joints in the overhead position in various thicknesses of plate using prepared edges.

27. Welding of rotated flanges to, and butt joints in, pipes of up to 4 in. (102 mm) dia.

Third year

Suggested specimens for macro-examination:

(*a*) Sections from an open square butt joint in $\frac{1}{4}$ in. (6·35 mm) or $\frac{3}{8}$ in. (9·35 mm) thick mild steel welded from both sides.
(*b*) Sections from single and multi-run $\frac{1}{2}$ in. (12·7 mm) mild steel fillet welds.
(*c*) Sections from any non-ferrous weld (not stainless steel).

28. Welding of butt and fillet joints using deep penetration techniques.

29. Butt welds in sheet mild steel—about 16 s.w.g. (1·63 mm).

30. Welding of intersecting seams.

31. Welding of cast iron with ferrous and non-ferrous electrodes.

32. Machineable cast iron butt welds—about $\frac{3}{8}$ in. (9·53 mm)–$\frac{5}{8}$ in. (15·9 mm) thick.

33. The hard surfacing of cast iron using the buttering technique.

34. Position welding of pipes to include butts, flanges and branches.

35. Surfacing of metals for heat, wear, abrasion and corrosion resistance, including, in particular, hard facing and tool tipping.

36. Carbon-arc welding of ferrous and non-ferrous metals.

37. Welding of butt joints in austenitic stainless steel sheet.

38. Welding of butt and fillet welds in low alloy high tensile steels with both austenitic stainless steel electrodes and low-hydrogen ferritic electrodes.
(A demonstration of hydrogen evolution from ferritic weld metals should be given at this stage by the instructor.)

39. Welding of butt joints in non-ferrous metals, *e.g.*, aluminium; copper and nickel; and their principal alloys.

40. Preparation of specimen work for examination.

Oxyacetylene Welding Technology

First year

General introduction

General survey and simple definition of the basic principles and processes of welding. Advantages and special use of each. Brief comparison of fusion and pressure welding with other methods of jointing metals.

Safety measures

Ministry of Labour and National Service Memorandum on oxyacetylene welding. Details of safety measures and care required in connection with operation of plant and equipment.

Gas plant

Properties of such gases; acetylene, coal gas, propane, hydrogen. Systems of generating acetylene, charging, gas yield, overheating and after generation, purification and testing for impurities, layout of generating plant, carbide store, acetylene pipeline and hydraulic safety valves.

Disposal of carbide sludge. Advantages and disadvantages of generated and dissolved acetylene. Storage and handling of cylinders, cylinder content and discharge rates.

Oxygen

Manufacture by liquefaction: properties, safe handling and storage, cylinder contents and discharge rates. Liquid oxygen, its transportation, handling, storage and distribution, evaporation rates.

Nitrogen and argon

Uses in welding technique.

Blow-pipes and flames

Choice of blow-pipe, available types for low and high pressure systems: construction, care and operation. Structure of the oxyacetylene and other oxy-fuel gas flames, variation of flame settings and their uses, effect of various flames (correct and incorrect), effect of nozzle size, gas pressure, gas velocity. Control of gas velocity and its influences on (*a*) welding and (*b*) backfiring. Other causes of backfiring and appropriate remedies.

Uses and applications of air-acetylene tools.

Gas pressure regulators

Single-stage and multi-stage types for fuels and other gases: their construction, care and operation.

Welding rods

Uses and types of filler rod for welding mild steel, with reference to appropriate British Standards.

Welding technique (mainly downhand)

(*a*) Blow-pipe and rod manipulation.
(*b*) Leftward welding, depositing fusion beads of weld metal, angles of blow-pipe and filler rod relative to plate, shape and size of deposited metal.
(*c*) Butt welds, types and methods of preparation, gap setting, maintenace of gap to ensure penetration; restarting the weld.
(*d*) Fillet welding—effect of shape, leg length and throat thickness, angles of rod and blow-pipe.
(*e*) Single operator vertical welds—angles of rod and blow-pipe, edge preparation, gap setting.
(*f*) Other types of weld joint to British Standards.
(*g*) Simple methods of avoiding distortion, weld sequence, direction of welding, back stepping, control of heat spread, use of chills.
(*h*) Use of clamps and jigs.
(*i*) Destructive tests; laboratory and workshop tests and *in situ*.
(*j*) Common weld defects (refer to BS.1295, Factors 1 to 8).

Fundamental principles of gas cutting

(*a*) History of gas cutting of mild steel.
(*b*) The cutting blow-pipe and its manipulation.
(*c*) Fuel gases used and types of nozzles required.
(*d*) Flame adjustment and correct gas pressures.
(*e*) Effect of nozzle size, gas pressure and speed of cutting on quality of cut surface.
(*f*) Types of hand cutters and cutting machines, preparation of welding edges.

Second year

Other welding techniques

(*a*) Rightward welding.
(*b*) Two-operator vertical welding.
(*c*) Multi-run welding.
(*d*) Block welding.
(*e*) All position rightward.
(*f*) Butt welds in ferrous pipe (including bottom run "arc-on-gas").
(*g*) Surface fusion (semi-fusion) welding.
(*h*) Workshop and visual methods of testing welds. (Refer to BS.1295 and 1821).
(*i*) Fusion welding, bronze welding, brazing and silver soldering, and their fundamental differences.
(*j*) The technique of welding grey and malleable iron castings by fusion and bronzewelding; expansion and contraction effects, preparation for welding, weld procedure, pre-heating and preheating methods, post-heating and after treatment. The welding of cast and high carbon steels.

Profile cutting

Types of machine, principles of operation, stack cutting, templets and templet allowances, extra-heavy cutting.

The influence of alloying elements in steel on cutting practice, with particular reference to carbon content. Use of preheating and slow cooling.

Third year

Workshop layout

Layout of workshop for gas welding, benches, pre-heating appliances, facilities for handling work, welding fixtures and manipulators. Gas plants, piping, manifold position of valves.

Technique

The technique of welding low and high alloy steels, austenitic stainless steel, copper and copper alloys, nickel and nickel alloys, aluminium and aluminium alloys, magnesium and magnesium alloys, galvanised steel, zinc diecastings. Lead welding. Brazing (including flame brazing of aluminium):

The use of fluxes: flux removal.
Hardfacing and the reclamation of worn parts.

Composition and types of rod for non-ferrous metals and hard facing and their applications, with special reference to their suitability for resisting wear by shock, friction, abrasion, erosion and corrosion.

The joining of dissimilar metals, *i.e.*, lead to steel, copper to brass and steel, aluminium to steel.

Powder injection

The powder injection process for cutting stainless steel and non-ferrous metals, oxygen lance and powder injection lance cutting and hole piercing.

Flame gouging

General principles and application.

Inspection and testing of welds

Defects in welds: faults due to manipulation, material and general conditions.

Testing

Tensile, bend and impact testing. Shear and tearing tests. Brief reference should also be made to other methods of testing including non-destructive tests, magnetic crack detection, X-ray, gamma ray, ultrasonic, acoustics, metallographic methods. (Reference should be made to "*Training and Testing of Welders*", BS.1295.)

Pressure testing. Testing of containers with liquids and gases. Safety precautions to be taken before, during and after testing.

Costing (simple treatment)

Factors influencing costs—consumption of gases, rods and fluxes, preparation, assembly, welding, speed of welding and post-operative treatment time. Labour costs and overhead expenes.

Practical Oxyacetylene Welding

First year

Note—All work in this section refers to *mild steel* only.

1. General description of workshop equipment with emphasis on the safety precautions to be observed in its use.
2. Setting up and operation of equipment:

(*a*) Fusion beads with filler rod on 16 (1·63 mm) gauge or heavier plate.
(*b*) Butt joints in $\frac{1}{16}$ in. (1·59 mm) up to $\frac{1}{8}$ in. (3·18 mm) thick plate, square edge preparation, correct gap setting.
(*c*) Butt joints in $\frac{3}{16}$ in. (4·76 mm) and $\frac{1}{4}$ in. (6·35 mm) plate, with 80° included angle.
(*d*) Fillet, lap and corner joints in all metal thicknesses as in (*b*) and (*c*).
(*e*) Rotated butt joints in pipes up to $\frac{1}{4}$ in. (6·35 mm) wall thickness and 4 in. (101 mm) diameter, all pipe ends prepared to 80°–90° included angle.
(*f*) Butt, tee and mitre joints in angle section.
(*g*) Butt and tee joints in $\frac{1}{4}$ in. (6·35 mm) dia. up to 1 in. (25·4 mm) dia. round bar.
(*h*) Oxygen cutting by hand. Use of the cutting blow-pipe on plate of various thicknesses and sections and in pipe ends. Sheet metal and cutting nozzles should be used.
(*i*) Instruction in the use of hand operated cutting machines.

Note—All welds (*a*) to (*d*) to be executed in the downhand, vertical, horizontal–vertical and overhead positions.

All the above welding to be by the leftward technique.

Preparation and types of joints to be according to relevant British Standards and students to use hand cutter and hand cutting machines for preparation of edges. Occasional joints to be examined as defined in BS.1295. Tests for the use in the training of welders as appropriate to thickness of metals concerned.

Second year

1. Butt and fillet welds on $\frac{3}{16}$ in. (4·76 mm), $\frac{1}{4}$ in. (6·35 mm) or $\frac{3}{8}$ in. (9·53 mm) mild steel plate, in the downhand position, by all position rightward technique.

2. Butt joints on $\frac{3}{16}$ in. (4·76 mm), $\frac{1}{4}$ in. (6·35 mm) or $\frac{3}{8}$ in. (9·53 mm) mild steel plate in the downhand, vertical, horizontal–vertical and overhead positions, by all position rightward technique.

3. Two-operator vertical welding on $\frac{1}{4}$ in. (6·35 mm), $\frac{3}{8}$ in. (9·53 mm) or $\frac{1}{2}$ in. (12·70 mm) mild steel plate.

4. Multi-run and block welding on $\frac{1}{2}$ in. (12·70 mm) plate.

5. Bronzewelded butt and fillet joints on $\frac{1}{16}$ in. (1·59 mm), $\frac{1}{8}$ in. (3·18 mm) and $\frac{3}{16}$ in. (4·76 mm) mild steel plate.

6. Fusion welds on $\frac{1}{4}$ in. (6·35 mm), $\frac{3}{8}$ in. (9·53 mm) or $\frac{1}{2}$ in. (12·70 mm) thick cast iron pieces on bench.

7. Bronze welds on $\frac{1}{4}$ in. (6·35 mm), $\frac{3}{8}$ in. (9·53 mm) or $\frac{1}{2}$ in. (12·70 mm) thick cast iron malleable iron pieces on bench.

8. Fusion and bronzewelding of iron castings preheated in loose fire-brick furnaces using charcoal, air–propane or air–coal gas bunsen burners.

9. Profile cutting to templet on oxy-flame cutting machine, including making simple templet to correct dimensions.

10. Stack cutting.

11. Butt joints on mild steel pipes up to 4 in. (101 mm) diameter; welded in the overhead, and horizontal–vertical positions, using the rightward and all-position rightward techniques.

12. Prepare by hand cutting, fit and weld equal and unequal branch pipe joints; branch to be located between 90° and 60°. Welds to be made in fixed positions.

13. Profile cut and weld of plate flange to pipe.

Note—Specimen work tests pieces Nos. 1, 2, 3 can be completed. Also 4 and 5, if desired. Preparation and types of joints to be according to relevant British Standard. Occasional joints to be examined as defined in BS.1295 as appropriate to thickness and metals dealt with, pipe work to BS.1821. In the case of fillet welds, one plate must be vertical.

Third year

Note—Macro-examination of a selected number of specimens is expected.

Suggested specimens for macro-examination:

(*a*) Sections from a single vee butt joint in $\frac{1}{4}$ in. (6·35 mm) or $\frac{3}{8}$ in. (9·53 mm) thick mild steel, welded from one side.
(*b*) Sections from $\frac{1}{4}$ in. (3·18 mm) and $\frac{3}{8}$ in. (9·53 mm) mild steel fillet welds single run.
(*c*) Sections from any non-ferrous welds (not stainless steel).

Defective as well as visually sound welds should be included.

1. Fusion butt joint in stainless steel in range of 16–20 gauge (1·63–0·914 mm).

2. Fusion butt joint in sheet brass and in copper $\frac{1}{16}$ in. (1·59 mm)–$\frac{1}{8}$ in. (3·18 mm). Fusion butt joint in aluminium and its alloys $\frac{1}{16}$ in. (1·59 mm)–$\frac{1}{8}$ in. (3·18 mm).

3. Bronze weld on $\frac{1}{16}$ in. (1·59 mm)–$\frac{1}{8}$ in. (3·18 mm) copper sheet.

4. Bell joint bronze welds on $1\frac{1}{2}$ in. (38 mm) or 2 in. (51 mm) dia. copper tubing.

5. Fusion butt and lap joints on 4, 6, or 8 lb lead sheet.

6. Butt joint bronze welds on galvanised sheet and tubes.

7. Brazing of aluminium and other metals.

8. Butt and fillet joints between dissimilar metals, *i.e.*, aluminium to steel, copper to brass, galvanised steel to copper and brass.

9. Demonstrations and practice using air-acetylene, oxy-coal gas, and oxy-propane heating and brazing blow-pipes.

10. Flame gouging for the removal of weld metal and for weld preparation.

11. Welding of non-ferrous castings. (Special attention to be paid to methods of flux removal).

12. Welding special steels.

13. Building up worn parts, *e.g.*, splines or gear teeth with nickel steel.

14. Demonstrations and practice with various types of hard facing materials, *e.g.*, wear resisting steels (*see* BS.1295) and cobalt base alloys deposited with excess acetylene flame.

15. Use of special bronze rods for resurfacing worn parts on ferrous and non-ferrous metals.

16. The detection of faults during welding. Indication of faults subsequent to welding, permissible corrections.

17. Methods of practical testing of welds.

18. Preparation of specimen work required for examination by the City and Guilds of London Institute's Local Examiner attending for the practical test.

Welding Science

(Notes are issued for the guidance of teachers with regard to the interpretation of the syllabuses.)

First year

1. Measurement of temperature; quantity and measurement of heat, specific heat, transmission of heat. Methods by which heat is generated for welding.

2. The solid, liquid and gaseous states of matter; change of state by heat, latent heat, cooling curves and the melting points of pure metals. Thermal expansion and contraction.

3. Introduction to simple chemistry; elements, atoms and molecules. Simple chemical reactions and the formation of compounds. Examples of common reactions occurring in welding processes.

4. Concept of exothermic reactions, combustion of carbon, hydrogen and acetylene.

5. Elementary treatment of solubility, saturation and precipitation.

6. Simple ideas of stress and strain in solids; illustration of tensile, compressive and shear stresses. Elementary consideration of the mechanical properties of metals; elasticity and plasticity, brittleness and hardness. Simple description of the effect of elevated temperatures on the mechanical properties of metals.

7. Introduction to crystalline nature of metals. Solidification of pure metal. Concept of crystal grains, grain boundaries and effect of temperature in promoting grain growth. Macroscopic and microscopic examination. Effect of grain size on mechanical properties.

Second year

8. The stress strain diagram; limit of proportionality (proof stress). Typical examples; ultimate tensile stress.

9. Consideration of thermal expansion and contraction as causing internal stresses and/or distortion in welded structures. The effect of the lowered limit of proportionality at elevated temperatures on distortion and internal stress. The relief of stress by annealing.

10. Oxidation and reduction, effect of high temperatures on chemical reactions. Formation of slags; deoxidation of liquid metals.

11. Action of atmospheric gases on liquid metals. Inert gases. The reactions common in welding and use of flux and flux coated electrodes.

12. Solubility, saturation and precipitation. Metallic solid solutions, inter-metallic compounds.

13. Introduction to thermal equilibrium diagrams, metallic solid solutions and intermetallic compounds. Simple description of eutectic and eutectoid transformations.

14. Typical structural changes in metals on heating and cooling with reference to thermal equilibrium diagrams. Illustration of such changes in common metallic alloys.

15. The relationship between micro-structure and mechanical properties.

16. Work hardening, general effects of cold working on structure and mechanical properties, stress relieving and annealing. Hot working.

17. The iron–carbon thermal equilibrium diagram. Characteristic microstructures of ferrous metals. Simple explanation of the critical range, normalising and annealing.

18. The effect of fast cooling on the structure and mechanical properties of steel. Tempering.

Third year

19. Changes in the structure and properties of steel due to welding grain growth, overheating and "burning".

20. Macro- and micro-examination of ferrous metals and structures of welds. Satisfactory and unsatisfactory structures.

21. Composition and properties of mild steel and cast iron. Typical examples of low alloy, air hardening and austenitic steels. Simple explanation of the effect of alloying elements in steel, particularly as affecting hardenability.

22. Changes in structure and properties caused by the welding of mild steel, cast iron and alloy steels. Effect of impurities introduced in welding, including oxygen, hydrogen, nitrogen.

23. Welding of copper and aluminium; changes in structure in the fusion zone, with reference to the relevant parts on the thermal-equilibrium diagrams. Macro- and micro-examination of welds.

24. Elementary treatment of the welding of common non-ferrous alloys, and the problems arising.

25. Simple description of age-hardening. Properties and composition of common precipitation hardening alloys. Welding of precipitation hardening alloys.

Welding Drawing

The aim of this section of the syllabus is the development of the candidate's ability to read and understand workshop drawings, and not the training of welding draughtsmen. Scale drawing, including orthographic projections and isometric or pictorial views, should be dealt with, and freehand sketching of gas and electric welding equipment and materials should be freely employed. Drawings and dimensions should be in accordance with Engineering Drawing Practice (BS.308) but it should be noted that elaborate or well-finished drawings will not be expected.

Second year

Instruction in the reading and understanding of workshop drawings. Drawings and dimensions should be in accordance with Engineering Drawing Practice (BS.308). Drawings of simple objects only to be attempted, such as welded brackets, surface developments in simple cases, *e.g.*, sections of cones and cylinders, simple jigs and fixtures for welding.

Third year

(*a*) Types of welded joint and the correct method of indicating welds on drawings to define essential information including operational sequence (*see* BS.499).

(*b*) Development of tanks, boxes, brackets and the like, bearing in mind conservation of metal and length of welding.

(*c*) More difficult subjects including sectional views. Development of pipe branches, junctions and segmental bends. Welding and cutting equipment.

Specimen Work and Practical Tests in Oxyacetylene Welding

A. Specimen work

Each candidate must, prior to the date of the examination, complete Tests Nos. 1, 2 and 3, and at least three others. The tests are to be carried out under the supervision of the staff of a technical college, and each test piece is to be clearly stamped with the candidate's identification mark. Each technical college submitting candidates must certify on the appropriate form that the specimens are the candidate's own unaided work. The testing and examination of the specimens is an integral part of the work to be carried out by the candidate.

The complete specimen work is to be retained in safe custody at the college for marking by the City and Guilds of London Institute's Local Examiner. A candidate whose specimen work is not considered satisfactory will fail in the examination as a whole.

1. Butt weld in the downhand position between two pieces of $\frac{1}{16}$ in. (1·59 mm) mild steel sheet. Width of sheets not less than 4 in. (101 mm), and the length not less than 6 in. (152 mm), with the weld on the long sides.

Test pieces to be examined as defined in BS.1295, Part 2, Test No. 1.

2. Fillet weld in downhand position in $\frac{1}{8}$ in. (3·18 mm) mild steel flat plates. The tee specimen 6 in. (152 mm) long to be made up of plates not less than 4 in. (101 mm) wide, and welded with a fillet along the centre line of the length of one plate.

Test pieces to be examined as defined in BS.1295, Test No. 6.

3. Outside corner joint in the vertical position between two 6 in. (152 mm) by 4 in. (101 mm) mild steel plates, $\frac{3}{16}$ in. (4·76 mm) thick, set at 90°.

To be broken open and examined for penetration and fusion of the root.

4. A butt weld between two lengths of 2 in. (50·8 mm) dia. steam pipe, with square end preparation and in fixed vertical position during welding. Each piece to be as long as reasonably possible, but in no case may each piece be less than 3 in. (76 mm). Pipe to be substantially in alignment after welding. Test piece to be examined as defined in BS.1295, Test No. 3.

5. The welding of two pieces of cast iron plate (or slabs) of not less than $\frac{3}{8}$ in. (9·53 mm) thickness by 4 in. (101 mm) long by $1\frac{1}{2}$ in. (38 mm) wide in the downhand position. The edges to have a bevel of approximately 45°.

After visual examination the cast iron to be fractured through the weld to disclose a sound dense deposit substantially free from blow-holes and porosity.

6. A butt joint in the downhand position between two flat pieces of copper sheet. Each piece to be approximately 6 in. (152 mm) long by 4 in. (101 mm) wide, of any thickness between $\frac{1}{16}$ (1·59 mm) and $\frac{1}{8}$ in. (3·18 mm), and welded on the long sides.

To be visually examined for weld contour, fusion, penetration and weld procedure.

7. A butt joint in the down hand position between two pieces of brass sheet. Each piece to be not less than 6 in. (152 mm) long and 4 in. (101 mm) wide of any thickness between 16 gauge (1·63 mm) and $\frac{1}{8}$ in. (3·18 mm), and welded on the long sides.

To be visually examined, etc. (as for No. 6).

8. Build up a pad of metal with wear-resisting steel on a plate 6 in. (152 mm) by 3 in. (76 mm) by $\frac{1}{2}$ in. (12·70 mm) thick. The pad shall be 4 in. (101 mm) by 2 in. (50·8 mm) and at least $\frac{3}{8}$ in. (9·53 mm) thick and consist of not less than two layers of runs of weld metal.

To be examined as defined in BS.1295, Test No. 9.

9. A butt joint in the downhand position between two pieces of stainless steel not less than 3 in. (76 mm) wide and 6 in. (152 mm) long by $\frac{1}{16}$ in. (1·59 mm) thick.

To be visually examined for weld contour and penetration.

B. Practical tests

Each candidate must complete the following tests, including the examination of the welds as stated, in the presence of the City and Guilds of London Institute's Local Examiner.

(*a*) Square edge butt weld in $\frac{1}{4}$ in. (6·35 mm) mild steel plate, not less than 4 in. (101 mm) wide and 10 in. (253 mm) long to be welded by the rightward technique with the weld on the long sides; to be visually examined for good root fusion, penetration, even build-up and lack of undercutting. To be tested as defined in BS.1295, Test No. 2, but only one transverse test piece to be used (test piece *B*) for a reverse bend test, *i.e.*, with the weld face in contact with the former.

(*b*) Weld together two bars of mild steel, each not less than 4 in. (101 mm) long and of $\frac{3}{4}$ in. (19·5 mm) or 1 in. (25·4 mm) dia. by a double-V butt joint. After visual examination the joint to be nick-sawn across the centre line of the weld and bent until broken. The fracture must show sound metal without blow-holes, cold laps or lack of fusion within the joint.

(*c*) A butt joint in the downhand position between two pieces of sheet aluminium. Each piece not less than 6 in. (152 mm) long by 4 in. (101 mm) wide by $\frac{1}{16}$ in. (1·59 mm) or $\frac{3}{32}$ in. (2·38 mm) thick and welded on the long sides.

To be visually examined for good weld contour, full and continuous penetration and cleanliness (*i.e.*, flux removal).

Note—(*a*) It is estimated that sixty or seventy minutes should be sufficient time required to weld the test pieces at the practical examination, leaving the remainder of the three hours available for testing.

(*b*) The dimensions of the pieces of metal required for the above have been carefully chosen in relation to the respective tests.

Preparation of the test pieces must be done by the candidates as part of the class work before the date of the practical examination.

Specimen Work and Practical Tests in Electric Arc Welding

A. Specimen work

Each candidate must, prior to the date of the examination, complete Tests Nos. 1, 2 and 3, and at least three others. The tests are to be carried out under the supervision of the staff of a technical college, and each test piece is to be clearly stamped with the candidate's identification mark. Each technical college submitting candidates must certify on the appropriate form that the specimens are the candidate's own unaided work. The testing and examination of the specimens is an integral part of the work to be carried out by the candidate.

The complete specimen work is to be retained in safe custody at the college for marking by the City and Guilds of London Institute's Local Examiner. A candidate whose specimen work is not considered satisfactory will fail in the examination as a whole.

1. Single-V butt weld between two mild steel plates not less than 6 in. (152 mm) long, 2–3 in. (50·8–76 mm) wide and $\frac{3}{8}$ in. (9·53 mm) thick. Welded on long sides in the downhand position. No sealing run.

Test pieces to be examined as defined in BS.1295, Test 2.

2. Close square tee joint in mild steel plate about 12 in. (304·8 mm) long, 2 in. (50·8 mm) wide and $\frac{3}{8}$ in. (9·53 mm) thick. Welded in the downhand position in three runs, first run 12 in. (304·8 mm), second run 8 in. (203·2 mm) and third run 6 in. (152 mm). Total weld size, for three runs combined $\frac{3}{8}$ in. (9·53 mm) leg length.

Test pieces to be examined as defined in BS.1295, Test 7.

3. Outside corner joint (90 degrees) in mild steel plate 6 in. long, about 3 in. (76 mm) wide and $\frac{3}{8}$ in. (9·53 mm) thick. Welded upwards in the vertical position. No sealing run.

After visual inspection to be broken open and examined for root penetration, lack of fusion and slag inclusions.

4. Single-bevel butt weld between two lengths of steam pipe about 3 in. (76 mm) dia. and in fixed vertical position during welding. Each piece to be as long as reasonably possible but in no case may each piece be less than 3 in. (76 mm). Pipe to be substantially in alignment after welding.

Test piece to be examined as defined in BS.1295, Test 3.

5. Single-V butt weld between two pieces of cast iron 6 in. (152 mm) long, 3 in. (76 mm) wide and $\frac{3}{8}$ in. (9·53 mm)–$\frac{1}{2}$ in. (12·70 mm) thick; initial layers with ferritic electrodes and final layers with electrodes producing machineable welds.

After visual inspection to be fractured through weld and examined for porosity, slag inclusion and lack of penetration.

6. Depositing a straight bead on a mild steel plate 8 in. (203·2 mm) square by $\frac{1}{2}$ in. (12·70 mm) thick; one inch from this bead, deposit five overlapping runs alongside one another. One inch from the overlapped runs, build-up a pad of weld metal 4 in. (101 mm) by 3 in. (76 mm) by $\frac{1}{2}$ in. (12·70 mm) high.

Pad to be cut and etched for visual examinations.

7. Single-bevel butt joint between two mild steel plates 6 in. (152 mm) by 3 in. (76 mm) by $\frac{3}{8}$ in. (9·53 mm) thick. Welded on long sides in the horizontal–vertical position. No sealing run.

To be examined as defined in BS.1295, Test 2.

8. Single-V butt joint between two mild steel plates 6 in. (152 mm) by 3 in. (76 mm) by $\frac{3}{8}$ in. (9·53 mm) thick. Welded on long sides in the overhead position. No sealing run.

To be examined as defined in BS.1295, Test 2.

9. Butt weld in non-ferrous metal or alloy plates about 6 in. (152 mm) by 3 in. (76 mm) by $\frac{1}{4}$ in. (6·35 mm) thick. Welded on long sides in the downhand position. No sealing run.

To be examined for appearance, weld contour, penetration and cleanliness.

B. Practical tests

Each candidate must complete the following tests, including the examination of welds as stated, in the presence of the City and Guilds of London Institute's Local Examiner.

(*a*)

(i) Single-V butt weld in $\frac{1}{4}$ in. (6·35 mm) mild steel plate not less than 12 in. (304·8 mm) long and 3 in. (76 mm) wide, to be welded in the downhand position on the long side; to be visually examined for good root fusion, penetration, even build up and lack of undercutting. To be tested as defined in BS.1295, Test No. 2, but only one transverse test piece to be used (Test piece *B*) for a reverse bend test, *i.e.*, with the weld face in contact with the former.

(ii) Single-V butt weld as in (i) including testing but in $\frac{3}{8}$ in. (9·53 mm) plate welded in the vertical position.

(*b*) Weld together two bars of mild steel each not less than 4 in. (101 mm) long and of $\frac{3}{4}$ in. (19·5 mm) or 1 in. (25·4 mm) dia. by a double-V butt joint. After visual examination the joint to be nick-sawn across the centre line of the weld and bent until broken. The fracture must show sound metal without blow-holes or lack of fusion within the joint.

(*c*) A butt joint in the downhand position between two pieces of stainless steel (18/8 type) or non-ferrous metal or alloy; each piece not less than 6 in. (152 mm) long by 3 in. (76 mm) wide by $\frac{1}{4}$ in. (6·35 mm) thick, and welded on the long sides. To be visually examined for good weld contour, full and continuous penetration and cleanliness.

Note—The dimensions of the pieces of metal required for the above have been carefully chosen in relation to the respective tests.

Preparation of the test pieces must be done by candidates as part of class work before the date of the practical examination.

APPENDIX 10—U.S.A.

No details of specific schemes for training the welding technician were submitted from the U.S.A.

Co-operative Study of Brittle Fractures in Service

Foreword

For some years now, Commission IX of the IIW, both directly and through a number of Sub-commissions, has been studying data related to cases of brittle fracture in service. These studies have dealt with various methods of assessing notch ductility of steel plates, the fundamental mechanics of brittle fracture and the relationship of notch ductility to the weldability of steels.

From the information thus collected, together with that obtained by individual members of the Commission in the course of their normal activities, there has emerged a considerable body of evidence on factors that affect brittle fracture in service. Should any further failures occur, it is highly desirable that information be made available in a form that will allow it to be compared with other similar investigations and studied in relation to the general problem of assessment of liability of structures to brittle failure.

Commission IX has therefore formed a new Sub-commission 'D', which consists of a small group of experts from a number of countries who are willing to provide assistance and advice in the manner of investigating any failures that may occur.

Members of the Sub-commission are as follows:

Mr. J. E. Roberts, Chairman (United Kingdom)
Mr. A. Audige (France)
Mr. G. M. Boyd (United Kingdom)
Dr. D. K. Felbeck (U.S.A.)
Mr. H. Herbiet (Belgium)
Professor K. Rühl (Germany) (Chairman of Commission IX)
Dr. G. Vedeler (Norway)
Dr. J. H. van der Veen (Netherlands)

It is not practicable for the Sub-commission to have members from all the countries represented on the IIW. Consequently an outline method has been prepared to assist in investigation of service failures, both in countries which are directly represented on the Sub-commission and in those which are not. This outline of the recommended method of investigation of any service failure has been prepared in the form of a summarised data sheet describing the main features that require examination; a corollary document explains how these fractures can best be examined.

Information on individual cases of failure should be compiled if desired with the assistance of the appropriate national member society of the IIW, in accordance with the indications given below and made available to that society.

The interest of the IIW in collecting this information is purely technical and its only concern is with the advancement of knowledge. It is therefore unnecessary for the data to include the names of persons, groups or places concerned in the case. In order that the maximum advantage may be obtained from such information, its publication may be desirable and permission to publish will be presumed.

However, the anonymity of the persons and groups concerned with the case will be scrupulously preserved. Any additional remarks which may be added to the data will be published only after consultation with the supplier of the data.

Data Desirable for Investigating Brittle Fracture in Steel Structures

1. General

Type of structure, nature of loading, general description of fabrication, any abnormal events in past history of the structure.

2. Circumstances of fracture

Steel temperature, wind and weather conditions, estimated stresses at the time of fracture.

3. Details of fracture

Origin, path, position and length of fracture. Appearance of the surface of the fracture.

4. Material in the region of fracture

4.1—*Parent plate*

Type of steel and thickness, with analysis, heat treatment condition, mechanical properties, microstructure (both as delivered and after fabrication).

4.2—*Weld metal and heat-affected zones*

Mechanical and metallurgical properties of weld metal and heat-affected zones.

5. Fabrication data

5.1—*Pre-treatment of material*

Details of any hot or cold forming or heat treatment of material during fabrication.

5.2—*Assembly sequence*

Design of joints associated with fracture, sequence of assembly, assessment of stress concentrations, inspection procedure during fabrication.

5.3—*Welding procedure*

Edge preparation for welding, method of welding materials used in welding, preheat and post-weld treatments, if any.

6. Comments by reporting organisation

7. Associated documents

Appended documents, plans, sketches, photographs.

Report IIS/IIW-61-60 (ex doc. IXD-14, 15 & 16-60) of Commission IX "Behaviour of Metals subjected to Welding", Sub-commission D "Brittle Fracture" of the International Institute of Welding. 607

Suggestions for Providing Data on Brittle Fractures

Because the object of the data sheet is to enable information to be collated from different sources, it is desirable that the interpretation of the various headings for data required, be uniform.

It is hoped that the following comments regarding completion of the data sheets will assist the organisations supplying data to fulfil this objective. Although for maximum utility the information should be as complete as possible, even incomplete data are useful.

1. General

In this section, information is required about the type of structure, so that the tendency to brittle fracture of different types can be noted. For example, it is necessary to know whether the structure is a bridge, a storage tank, a ship, or a smaller item such as a shaft or individual structural element, and whether it is welded or riveted or a mixture of the two, or fabricated by some other means. It is also desirable to know whether, in the past history of the structure, there have been any events that may have contributed to brittle fracture. Examples are: local cold working during fabrication by such means as hammer indentations; general deformation resulting from an accident that may have distorted some of the members, etc.

2. Circumstances of fracture

One of the most important features in respect of the circumstances of fracture is the temperature at the time fracture occurred, because the tendency to brittle fracture is increased as the temperature falls. It would be useful to know whether the failure occurred:

(*a*) During initial fabrication
(*b*) In service.

In the latter case, it is important to know whether the structure was working normally or whether some abnormal conditions prevailed at the time of fracture. While it is realised that estimates of load or stress may not be very accurate, an indication of their order of magnitude is desirable. If there does happen to have been a more precise measurement of stress, then this value should be given and the fact that it was measured should be stated. Where possible, the average stress and the stress at the origin and arrest of the fracture should be given. The stresses arising from permanent or temporary temperature gradients in the structure should not be ignored in this context.

Any noises heard or other observations of witnesses should be reported.

If no immediate record of temperature and weather conditions is available, information on the date and place of the failure should enable such general information to be obtained from the meteorological departments of the country concerned.

3. Details of fracture

The main characteristics of a brittle fracture are

—high speed of crack propagation
—the absence of appreciable deformation at the edge of the fracture
—a predominantly crystalline appearance.

The report should state whether such features are evident.

The details of the origin and path of fracture, including the location of any noticeable changes in texture or profile, should be given as completely as possible with sketches. A note of any joints traversed by the crack and the proximity of the fracture to any other structural members should be included. In order to confirm the brittle nature of the crack, a photograph as well as a line drawing, would be very helpful.

The origin of a brittle fracture can usually be determined by the appearance on the fractured surfaces of chevron patterns which point back toward the origin.

The extent of the fracture relative to the total cross section of the structure should be indicated. It is important to specify whether the fracture started from an existing crack and particular note should be made of the location and direction of the fracture in relation to welded joints. When the origin or position of the fracture appears to be associated with a weld, metallographic examination is useful to determine whether the fracture started and/or propagated in deposited weld metal or in the weld heat affected zone. Moreover, a careful examination should be made at the origin of fracture to determine whether there are abnormalities present that might account for fracture initiation such as an arc strike, weld undercut, dimpling from a peening operation or a prior weld crack.

4. Material in the region of fracture

Data on material properties should be given for each plate affected by the crack and a note should be made of whether the crack originated in the material described, traversed it completely, or was arrested in it. In general, a table of properties will be required for every plate or other component involved in the fracture.

Tests on material from the fractured regions are necessary because the properties of material supplied to the fabricator may have been changed by fabrication procedures. The properties of the material as supplied are nevertheless important and certain information on this subject can be obtained only from the manufacturer of the material.

Where tests pieces are taken from material close to the fractured surface, the direction of the test pieces relative to the crack and also relative to the direction of rolling of the material, where this is known, should be given, preferably by means of a sketch.

4.1—*Parent plate*

(i) *Manufacturing procedure*

It is useful to have as much information as possible about the process by which the steel was manufactured, including deoxidation practice. The plate thickness should be given since this has a considerable bearing on the properties of plate of a given composition and method of manufacture. It may also be useful to quote the specification to which the steel was ordered.

(ii) *Analysis*

The chemical analysis should be taken from material involved in the fracture and as near as possible to it. The location, relative to the crack, of the samples analysed, should be indicated.

Similarly, the McQuaid-Ehn grain size should be determined, or, alternatively the results of tests on the original material may be given.

(iii) *Heat treatment condition*

Under this heading, it is desired to know whether the plates or other components were supplied in the as-rolled, normalised, quenched and tempered or other condition.

(iv) *Microstructure*

The microstructures are best illustrated by photographs. It is suggested that a standard magnification of $\times 100$ should be used unless there are particular features of the structure that require higher or lower magnifications in order to make them evident. This examination also should be conducted on material as close to the fracture as possible. The plane of the microstructure relative to the crack and the rolling direction of the material (when known) should be stated.

(v) *Mechanical properties*

The mechanical properties in the tensile test should be measured on samples taken from the fractured structure. Test results from the original test certificate for the material are also of interest. It should be made clear when providing these data which of these two alternative procedures has been adopted for providing the information.

Results of notch ductility tests made on the material when it was supplied might be obtained from the manufacturer's test certificates. In addition, it is very useful to carry out notch ductility tests on material which fractured, and if possible such tests should be run so that the direction of fracture in the test is parallel to the service fracture.

In all cases the direction of the test pieces relative to the fracture and to the rolling direction of the material, if this is known, should be stated. It is very desirable that the tests conducted in any special examination should include both measurements of energy absorption and an assessment of fracture appearance characteristics.

While there are many tests for energy absorption, the Charpy V-notch impact test is to be preferred if only one test can be made since it is laid down in many specifications and has been widely employed in previous investigations. This test is normally used to provide a measure of the energy absorption. However, the fractured specimen can also be used for measurement of the proportion of the fracture surface that has failed in a crystalline manner at the test temperature.

It is desirable that complete temperature transition curves be obtained by carrying out tests over a range of temperatures wide enough to include the temperature of the failure itself.

For a test confined primarily to fracture appearance a notch-tensile test, such as the Tipper test, or the slow notch bend test, such as the van der Veen test, is useful. These tests should be carried out over a range of temperatures that includes the temperature at the time of failure. Full results should be provided.

Facilities for conducting larger scale tests, such as the Robertson crack arrest test, are rare, but where they exist, data of this type are valuable.

A summarised outline of the various tests for notch ductility discussed above and a number of others, together with references to a fuller description of these tests and their methods of usage, are contained in the report of Sub-Commission A "Comparison of brittle fracture tests" of Commission IX (Doc.IIS/IIW–18–59 ex doc. IX–214–58).

Any other test data, such as the results of nick-fracture tests for homogeneity, inclusion counts and so on should also be presented when available.

4.2—*Weld metal and heat affected zones*

(i) *Mechanical and metallurgical properties*

The properties of the weld metal and of the heat affected zones of the parent plate can influence the initiation of brittle fracture, so information on the microstructures encountered, hardness, tensile strength and notch ductility of these areas is desirable.

Any evidence of heat-affected zone cracking in its various forms would also be useful, together with the results of any weldability tests that may have been carried out.

(ii) *Weldability tests*

Weldability tests fall into two main classes:

(*a*) Tests concerned with the local effects of welding—for example, underbead cracking, heat affected zone hardness, etc. (*e.g.*, The British Welding Research Association's Controlled Thermal Severity test)

(*b*) Tests concerned with the general behaviour of a welded component—for example, bead on plate bend tests (*e.g.*, Kommerell Bend test).

Tests of both classes made on material taken from the region of the fracture can provide useful information and results should include a note on the position of the material tested relative to the fracture.

5. Fabrication data

5.1—*Pre-treatment of material*

The properties of material can be altered by the processes used in preparing it for final assembly. Therefore any information on hot or cold forming and heat-treatment of material during fabrication (for example, hot pressing or stress relieving) should be given.

If there are available the results of any mechanical or metallurgical tests carried out on material before and after such operations these should be given.

Also included in this section should be information regarding the method of preparation for welding, for example, whether by gas cutting or planing, and similar information for other methods of assembly, for example, if riveted joints are involved, whether the rivet holes were drilled or punched, and so on.

5.2—*Assembly sequence*

It is desirable to determine whether the method of assembly has any influence on the fracture. The information required about assembly is probably best given by an annotated drawing. An assessment of stress concentrations near the fracture should draw attention to design features that may be relevant. Data on inspection procedures and their application would be valuable.

5.3—*Welding procedure*

The joint preparation and sequence of welding are of interest (shape of the prepared edges, number of weld runs used to complete the joint, etc.).

It would also be useful to know the process by which welding was carried out, that is, whether by hand, automatically or by combination of these methods. In addition information about welding conditions in terms of the type of electrode (whether low-hydrogen coated, rutile coated or some other type), whether a.c. or d.c. was used, and, in the latter case, whether the electrode was positive or negative, would be valuable. The need for information on preheating and any post-weld treatment, such as local post-heating to avoid excessive hardening or any form of stress relief or tempering treatment, is obvious as these may well affect the subsequent behaviour of the plate concerned.

It would also be useful to include details of any peening treatments between runs, or similar operations.

6. Comments by reporting organisation

It would be useful to include under this heading any other information available and, in particular, any conclusions reached regarding the means of preventing further fractures, or the cause of the particular fracture under discussion.

7. Associated documents

Supporting documents such as plans, photographs or other material containing information pertinent to the structure or its failure should, if possible, be appended.

Reports on Fatigue Failures

Fatigue phenomena may affect welded as well as other constructions. Consequently, whenever a welded assembly is required to withstand cyclic stresses, those responsible for its manufacture should insure that the appropriate measures analogous to those considered indispensable in non-welded products, are taken.

Among the great variety of types of assembly made possible by welding, may be some of equivalent static strength in service but which behave very differently under fatigue loading. Although further progress in this field may still be made, it is now known which of these types of assembly are to be recommended and which to be avoided. Commission XIII (Fatigue Testing) of the International Institute of Welding has collected critical reports on fatigue failures occurring in service in welded constructions in order that relevant information on this subject may be placed at the disposal of manufacturers. Some of these reports have been circulated for publication, following the Madrid meetings in 1956, the Essen meetings in 1957, and the Vienna meetings in 1958. At the Opatija meetings in June/July 1959 the Commission recommended the reports attached for publication.

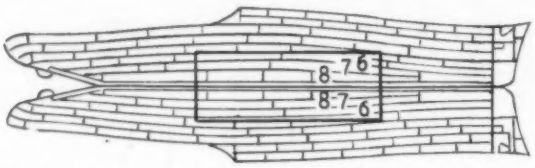
These reports are all presented in the same form corresponding, in so far as possible, to the questions in the inquiry circulated by the Commission with a view to obtaining the information which it wished to assemble. No information is given concerning the origin or author of these reports since the information was collected on the understanding that it would be considered as having been supplied anonymously and the Commission has acted on this understanding.*

FAILURES OF THE BOTTOM PLATING OBSERVED ON LOW-TONNAGE MOTOR VESSELS

1. Type of contruction affected

The failures (Fig. 1) occurring in the zone situated below the engine bearers, affected the bottom plating of vessels of small tonnage with the following characteristics:

Displacement	650 tons
Speed	19 knots
Power	4,000 h.p., at 440 r.p.m.



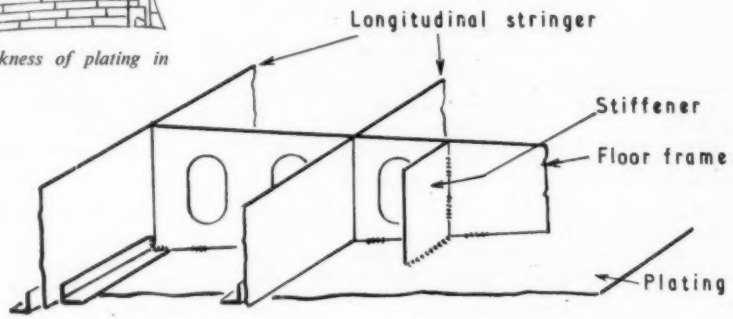
1—*Developed area of shell plating. Thickness of plating in damaged zone 6, 7, and 8 mm*

The bottom plating of these vessels, having a nominal thickness of 8–6 mm, consisted of longitudinal strakes with riveted longitudinal joints and welded end joints.

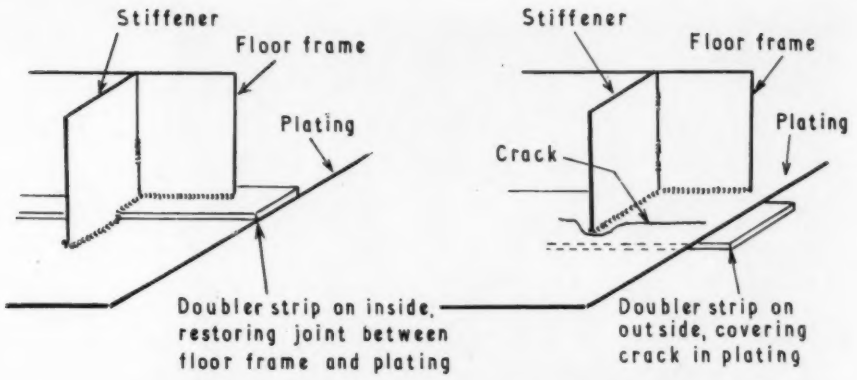
At the bottom, this plating was supported by floor frames to which it was intermittently welded (Fig. 2) and by longitudinal ribbands, fastened to the plating by means of riveted angle irons.

The floor frames carried web stiffeners which were welded to the plating.

* *International Welding*, 1961, No. 1, p. 16*s*.
Report IIS/IIW–39–60 of Commission XIII "Fatigue Testing" of the International Institute of Welding. 629b

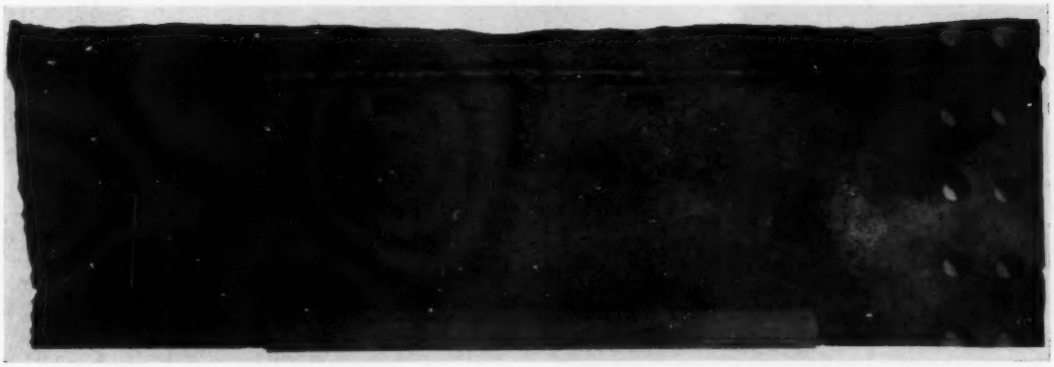


2—*Typical ship's bottom assembly*

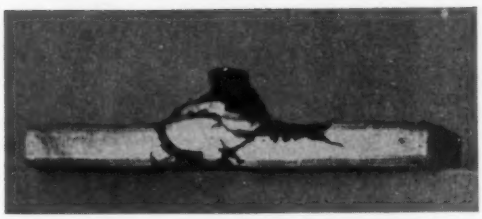


3—*Remedial measures tried out*

4—*Inside of plating* ×0·2



5—*Inside of plating* ×0·2



6—*Fracture section. Having originated on the inside, the fracture has extended in several directions as a result of internal and external corrosion* ×0·8

Figs. 4–6—*Examples of type* a *fractures*

2. Stresses in normal service in the zone affected

2 . 1—*Type of stress*

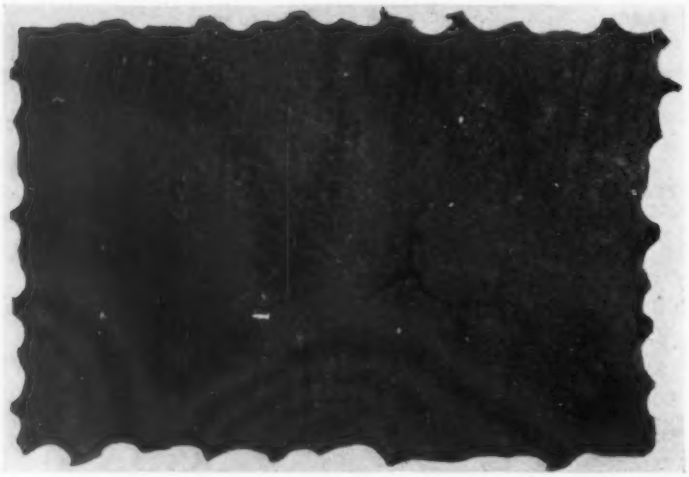
In this special case, the fact that the damage was confined to the zone below the engines prompts the thought that the damage may have been due to stresses caused by the engine vibrations.

2 . 2—*Amplitude and frequency*

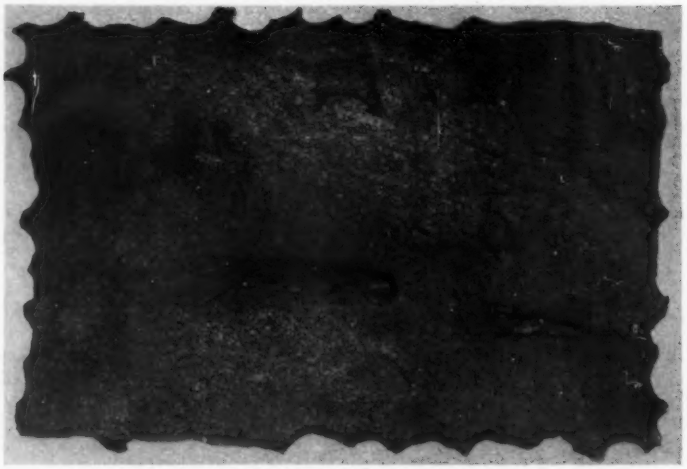
Neither the amplitude nor the frequency of the stresses were specially investigated.

2 . 3—*Total duration of stress application*

The only data available in this respect are the

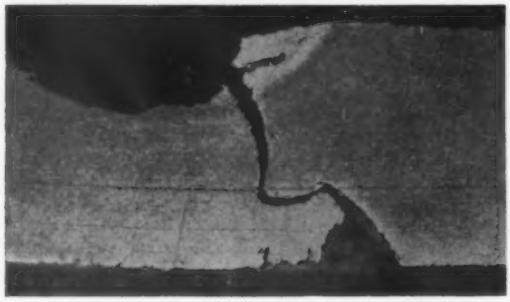


7—*Outside of plating*



8—*Inside of plating*

Figs. 7–9—*Examples of type* b *fractures*
9—*Longitudinal section across fracture* ×5



number of years during which the vessels had been in service at the time when the damage was discovered. These data are summarised in Table I.

3. Information concerning the fractures and the circumstances of their appearance

Most of the cases of damage were discovered when the vessels were docked.

3 . 1—*Position of the fractures*

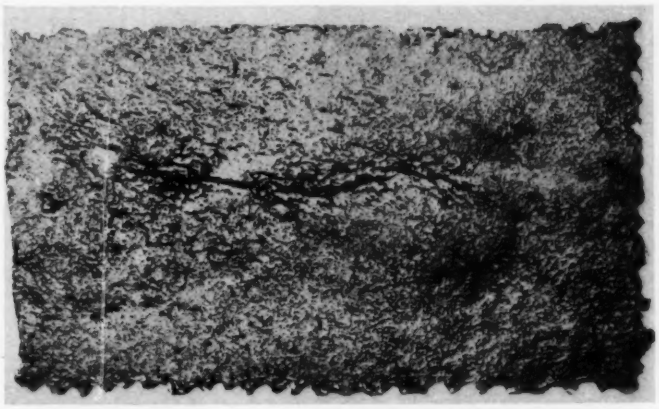
The fractures occurred in the plating itself or in the welds joining the floor frames to the plating, so that the floor frames came loose.

Table I

Time of detection, and number of plating fractures observed on each vessel

	Number of Years in Service					
	3	4	5	6	7	8
A	1			1	8	
B			2			
C			1		3	
D			1			
E						4
F	2				2	
G				3	3*	
H			1	1	2†	
I	1					3‡

* In addition: 11 floor frame weld fractures
† In addition: 5 floor frame weld fractures
‡ In addition: 14 floor frame weld fractures



10—*Outside of plating*

Figs. 10–11—*Example of type* c *fractures*

11—*Longitudinal section* ×4·5

12—*Example of type* d *fracture. Inside of plating* ×0·2

13—*Example of banded structure. First steel of Table II* ×100

3 . 2—*Extent of the fractures*

The fractures in the floor frame welds were liable to affect the floor frames over a comparatively long distance.

In contrast, the bottom plating fractures always remained comparatively short (less than 200 mm). In particular, they never degenerated into extensive, partially brittle fractures, even in the most brittle plates.

3 . 3—*Appearance of the fractures*

With plating fractures, four different types can be distinguished.

To type (*a*) belong the transverse fractures, generally skirting more or less closely the end of a welded stiffener (Figs. 4–6).

Type (*b*) comprises fractures which originated at the end of an intermittent weld seam serving to fasten a floor frame to the plating (Figs. 7–9).

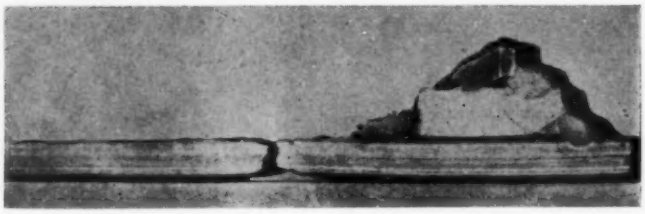
Type (*c*) comprises certain transverse fractures which originated in the plating between the floor frames. These fractures are accompanied by a network of parallel fissures which do not extend right across (Figs. 10 and 11).

Finally, type (*d*) comprises fractures formed across the rivet holes in the vicinity of the welds (Fig. 12).

Generally speaking, the appearance of these fractures

14—*Example of irregular grain structure. Second steel of Table II* ×100

16—*Longitudinal section across doubler strip under floor frame*



15—*Insertion of doubler strip between inside of plating and floor frame*

is similar to that of fatigue fractures encountered in a corrosive medium (corrosion fatigue).

3 . 4—*Deduction from the appearance of the fractures concerning the rupture process*

The appearance of the fractures indicates that the framework of the vessel was subjected to vibrations due to the action of the engine. As far as corrosion is concerned, this can be ascribed to the action of the seawater outside, or lying stagnant in the bottom of the vessel.

The position of the fractures raises the question of the weakening of fatigue strength associated with welded T-joints.

3 . 5—*Abnormal circumstances which may have accompanied the failure*

There is nothing to report in this connection.

3 . 6—*Remarks concerning practical experience with other similar constructions*

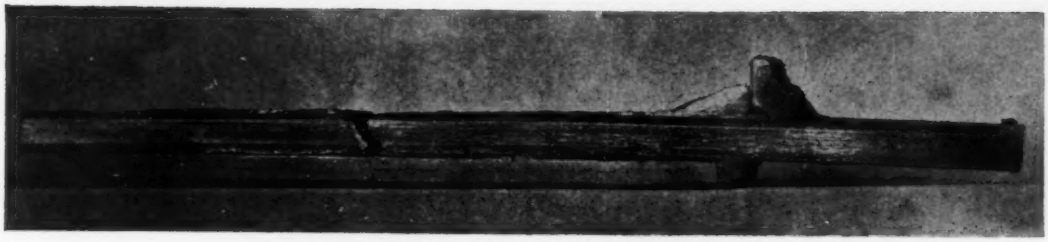
The damage is of a systematic nature as it occurred, at a fairly early stage, in 9 vessels of the same type (Table I).

Table II

Characteristics of steel

Sample from Vicinity of Fracture Type:	*Mechanical Properties*				*Chemical Analysis, %**				
	E, kg/mm²	*R*, kg/mm²	A_5, %	*K Mesnager*, kg.m/cm²	*C*	*Mn*	*Si*	*P*	*S*
a	31·4	42·0	18·2	0·62 min. 10·3 max	0·09	0·54	0·26	0·091	0·049
b	38·4	52·6	13·8	7·8	0·20	0·61	0·17	0·032	0·020
c	30·3	37·7	23·3	12·3	0·091	0·3	0·037	0·036	0·041

* No Cr or Ni contents



17—*Longitudinal section across external doubler strip*

4. Composition of the materials in the damaged zone

All these vessels were built of Thomas steel. Some of its characteristics are shown, by way of example, in Table II.

These steels have a variable structure.

The texture may be definitely banded (Fig. 13), or the grain structure may be very irregular (Fig. 14).

5. Type of joints affected

The fractures occurred not only in welded joints but also in the parent metal and across the rivet holes.

All the welds concerned were fillet welds, serving to fix the web of a floor frame or a stiffener to the plating. The welding conditions are not known.

6. Presumed causes of the damage, and deductions which may be drawn from it

The fractures observed must be largely ascribed to the vibrations caused by the engine.

When, due to these vibrations, the floor frames become detached from the plating owing to the rupture of the intermittent welds joining them, the amplitude which the plating is liable to assume increases, and cracks may appear in the parent metal itself. In other cases, these cracks remain confined to the end of the weld seams of the floor frames, or their stiffeners.

To repair the damage, an attempt was made, first of all, purely and simply to weld the cracks, and then to provide doubler strips on the inside or outside as shown in Fig. 3. These measures proved to be wholly unsuccessful (Figs. 15–17).

The only measure which proved to be effective was the replacement of the welded joints between floor frames and plating by riveted joints with double foot angle iron. The improvement then observed appears to be due to the capacity of the riveted joints to attenuate the amplitude of the vibrations caused by the resonance of the engines.

OBSERVATIONS ON FRACTURES OF WELDED WATER TANKS OF LOCOMOTIVE TENDERS

The water tanks of locomotive tenders are subjected to two kinds of stresses in service:

(1) Static stresses which are not very high as the water level never reaches 2 meters, and
(2) Dynamic stresses which may be very high (due, for example, to jolts and changes in running speed).

The shifting of the mass of water sometimes results in violent shocks, especially against the rear wall of the tank and against the breakwater devices placed inside it.

Up to 1927, the different components of the structure of the tank were assembled by means of riveted angle irons (Fig. 1).

With these tenders, fatigue fractures were often encountered in the baffle plates and in the rear wall, at the level of the angle iron (Fig. 2).

The first construction of a welded water tank dates back to 1927. For a tender with small water volume (7 m^3) which proved to be satisfactory in service, no particular conclusions can be drawn from experience with this first tank.

A second design, for tenders of 38 m^3 was undertaken in 1933. The tanks were assembled by a combination of welding and riveting. Experience with these tenders was not satisfactory; broken frames, distorted tanks and broken weld seams were observed.

These incidents did not implicate the principle of welding but arose from the actual design of the tank, which included the assembly of plates of very different thickness and inadequate bracing to prevent the welds from straining under the alternating bending moments.

In 1945, two manufacturers were entrusted with the production of wholly welded water tanks.

First experience with welded water tank

The principal aim of the assembly design was to facilitate the production process, both from the boilermaker's and the welder's point of view.

This result was obtained by adopting:

Report IIS/IIW–40–60 of Commission XIII "Fatigue Testing" of the International Institute of Welding. 629c

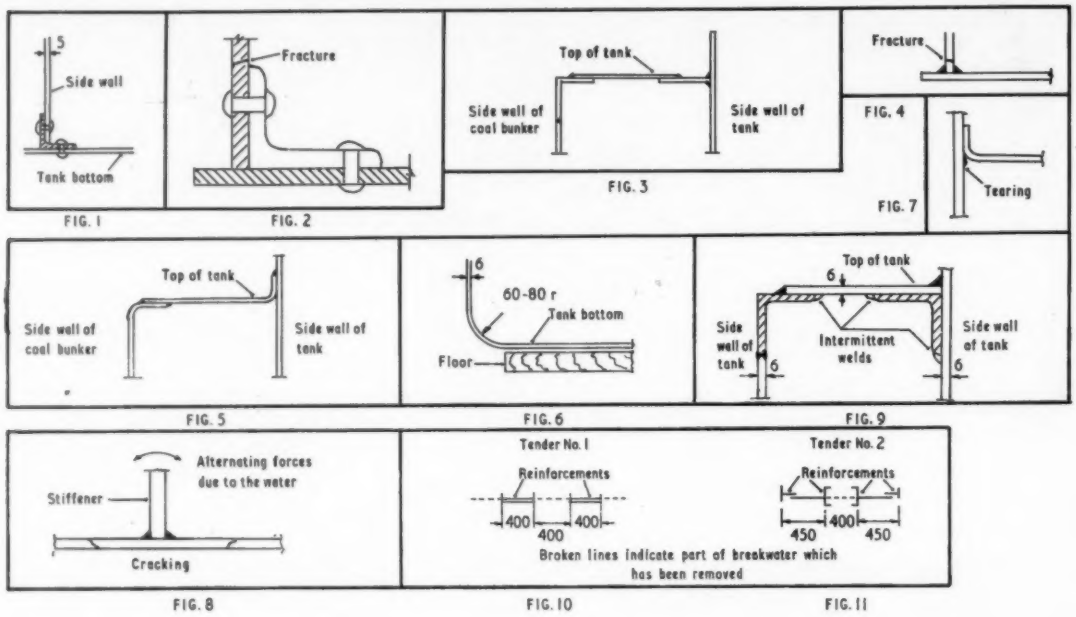


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 7 FIG. 5 FIG. 6 FIG. 9 FIG. 8 FIG. 10 FIG. 11

—the angle assembly method which avoids all bending or shaping work (Fig. 3),
—the overlap assembly method which does not call for a high degree of precision in cutting the sheets and which reduces the amount of bevelling (Fig. 3).

After the tenders had covered comparatively short distances (approx. 15,000 km), fatigue fractures were encountered in the rear wall and in the breakwaters, at the weld (Fig. 4).

Second experience with welded water tank

The assembly was more rational than in the first case but called for a greater amount of boilermaking work and more careful welding.

Thus,

—the flanged edge assembly called for perfect bending (Fig. 5),
—the butt welded assembly, which has certain advantages in respect of elasticity and resistance to corrosion (Fig. 6), called for important preparatory work.

Again after a comparatively short distance (approx. 15,000 km), the tanks showed numerous cases of damage:

—cracking at the edge of the weld reinforcement and in the cold worked zones of the flanged edges; these cases of damage were due more to the indifferent quality of the steel used than to the design of the assembly;
—tearing of the inner weld of the flanged edges (Fig. 7).

The method of fastening the plates was not adequate to enable them to resist the alternating bending stresses.

—cracking of the wall, loosening or tearing of the weld seam (Fig. 8).

The stiffening and bracing system was insufficient, flats being used.

—cracking of the rear wall and baffle plates and, even, rupture of the weld seam.

In the light of the experience gained with these two trial designs, it was subsequently decided to proceed, inspired by American designs, with the construction of two new welded prototypes.

The assemblies adopted were as shown in Fig. 9, the design undergoing a number of modifications:

The stay bars were replaced by gussets which stiffen the walls, the bottom and the roof.
The interior partitioning was reinforced.
All the angular assemblies were stiffened by angle irons.
The flats were replaced by T profiles for the stiffening of the walls.

The two tenders put into service in 1947 have given rise to the following findings:

After a distance of 33,000 km (tender No. 1) and 88,000 km (tender No. 2), the first cracks have appeared on the baffle plates level with the welds.

In order to overcome this, the breakwaters were modified:

—their width was reduced;
—the remaining part was reinforced by T profiles or channels fixed by continuous or intermittent welding (Figs. 10 and 11).

Since these modifications were carried out, the two tenders have been satisfactory in service.

At the end of 1958, they had covered:

1,100,000 km in the case of tender No. 1.
430,000 km in the case of tender No. 2.

Conclusion

The wholly welded water tanks of locomotive tenders appear to be satisfactory.

This result has been achieved while adhering to design arrangements much akin to those of riveted water tanks, but increasing the rigidity of the tank by adding gussets or profile stiffeners at the points exposed to the greatest stresses.

FRACTURE OF A LORRY FRAME LONGITUDINAL MEMBER

1. Type of construction in which failure occurred

On the frame of the lorry concerned, a loading box had been placed. For this purpose, the coach-builder had welded, to the longitudinals, angle irons to which the box was bolted. It should also be noted that the frame was extended towards the rear.

2. Stresses in normal service

No particulars are available as to the stresses existing at the point of fracture (*cf.* Fig. 6).

2 . 1—It would, however, seem that the main stress in the longitudinal is a bending stress.

2 . 2—Owing to the extension of the frame, the centre of gravity of the load was shifted towards the rear axle so that the bending stresses towards the centre of the frame were much smaller than those envisaged by the designer.

2 . 3—The lorry had covered 30,000 km.

3. Information concerning the fracture and the circumstances of its appearance

3 . 1—The position of the fracture in relation to the vehicle as a whole is shown in Fig. 6. Figures 1 and 2 provide a closer view.

3 . 2—The fracture affected the whole cross-section of the longitudinal.

3 . 3—Figures 3 and 4 provide a clearer picture of the fracture where the origin of the fatigue crack can be clearly seen (arrow in Fig. 4). This point is marked *A* in Fig. 3, and it may also be noted that, starting from *A*, the crack extended towards the zones *B* and *C*. Beyond *B*, the crack developed into a brittle fracture until the rupture of the entire cross-section was completed.

Report IIS/IIW-41-60 of Commission XIII "Fatigue Testing" of the International Institute of Welding. 629d

Fig. 1

Fig. 2

Fig. 3

Fig. 4

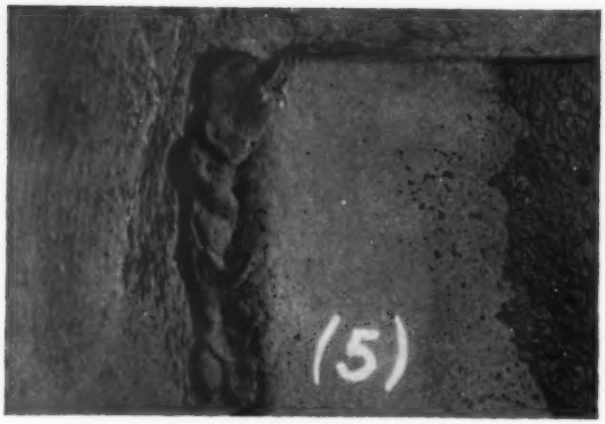


Fig. 5

It will be noted that, at the location of the fracture, the predominant stresses are flexural stresses towards the bottom which should have caused the failure of the lower flange of the longitudinal; yet it is in the upper part that the crack originated because of the notch effects and the local excess stresses caused by the weld seam.

3 . 5—The failure was not accompanied by any abnormal circumstances.

4. Materials

The steel of the longitudinal had a Brinell hardness of 135; its thickness was 5 mm.

5. Conditions of welding

Unknown.

6. Presumed causes of failure

The failure must be primarily ascribed to two facts:

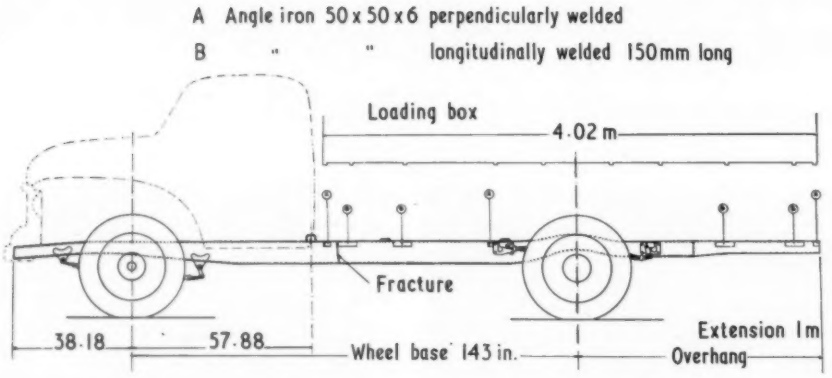


Fig. 6

3 . 4—It is noteworthy that the initial crack originated exactly at the edge of the weld seam, which it followed.

It will also be seen that the welds joining the angle iron to the longitudinal are only partial and contain undercuts which are all the more serious as the thickness of the metal of the longitudinal is small (*cf.* Figs. 2 and 4).

(1) the arrangement of a weld seam giving rise to a notch effected far from the neutral axis of a profile subjected to flexural stresses;

(2) the arrangement whereby the load path from the box through the angle irons to the longitudinal must pass through two lengths of welds, which gives rise to local excess stresses.

Observations on the Results of Torsion Relaxation Tests carried out on Four Typical Heat-Resisting Steels

By Dr. P. Brozzo (Italy)

Foreword

RELAXATION tests under torsion load were carried out on the following heat-resisting steels:

Steel *A* 0·75% Cr; 0·5% Mo—normalised and annealed
Steel *B* 2·25% Cr; 1% Mo—annealed
Steel *C* 5% Cr; 0·5% Mo—annealed
Steel *D* 13% Cr—air hardened and tempered.

A shear stress τ_0 corresponding to the conventional yield point $\sigma_{0.2}$, *i.e.*:

$$\tau_0 = 0{\cdot}577 \cdot \sigma_{0.2} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

was initially applied to the specimen at room temperature, the value of the torque T_0 being calculated, in the elastic range, by the formula:

$$T_0 = \frac{\pi d^3}{16} \cdot \tau_0 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

(d=specimen dia.=10 mm)

Plotting the amount of relief against temperature, curves were obtained that suggest some interesting considerations. Thus, it was recognised that all the results were in accordance with other properties of the materials under examination, such as the behaviour of elastic limit against temperature and creep strength.

In order to throw more light on the latter points, additional tensile tests at several temperatures were carried out on two types of steel.

Test equipment

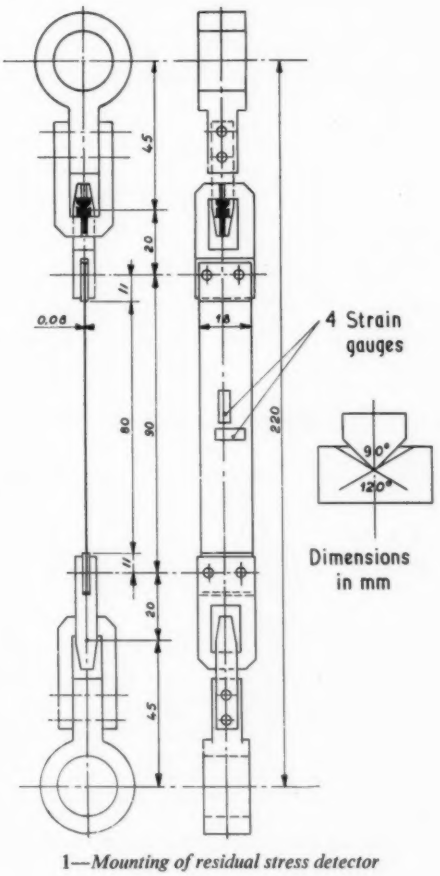
A relaxation machine not substantially different from that first described by Wellinger was used. However, it is to be noted that high accuracy in the measurement of relieved stress was gained as a result of the very careful design of the residual torque detector.

This consisted of a very thin spring steel strip, whose ends were supported in such a way as to undergo exclusively the tensile load transmitted by the specimen during relaxation (Fig. 1), this load being measured by four Baldwin SR.4–A7 strain gauges.

The latter were so wired that circuit output could not be affected by any casual bending stress on the strip.

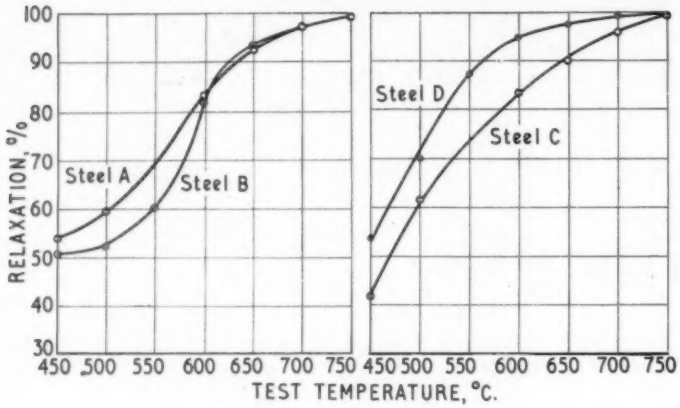
Experimental errors were minimised by means of the above device and satisfactory repetition of the results was achieved.

Great care was also devoted to temperature control. A Leeds–Northrup proportional-action controller was used for regulation and a check showed that temperature errors did not exceed ±2°C. through the whole length of the specimen.

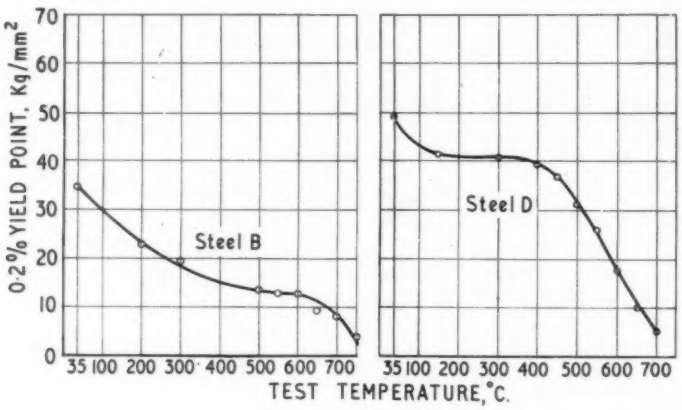


1—*Mounting of residual stress detector*

Report IIS/IIW–73–61 (ex doc. X–229–59) of Commission X "Residual Stresses and Stress Relieving" of the International Institute of Welding.
Dr. Brozzo is in the Research and Inspection Laboratory of the Ansaldo Co., Genoa, Italy.



2—*Relaxation curves after 20 hours*



3—*Yield point against temperature for* B *and* D *steels*

Materials under examination

(*a*) *Chemical composition, %*

Steel	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*S*	*P*
A	0·155	0·44	0·23	0·75	0·20	0·60	0·01	0·017
B	0·09	0·47	0·40	2·30	0·19	1·12	0·021	0·015
C	0·09	0·50	0·31	5·10	—	0·44	0·014	0·016
D	0·105	0·54	0·51	13·05	0·20	—	0·014	0·017

(*b*) *Mechanical properties* (*room temperature*)

Steel	*Ultimate Tensile Strength, kg/mm²*	*Yield Point 0·2% kg/mm²*	*Elongation, A 5%*	*Reduction in Area, %*
A	51·6	35·6	29·8	70·8
B	47·8	26·0	32·8	77·8
C	49·1	20·0	30·4	69·8
D	70·7	49·2	25·0	68·6

(*c*) *Heat treatment of samples*

Steel	*Austenitising Temperature, °C.*	*Holding Time*	*Cooling Medium*	*Tempering Temperature, °C.*	*Holding Time*
A	910	25 min	Air	720	3 hr
B	915	3 hr	Furnace	none	—
C	900	3 hr	Furnace	none	—
D	980	25 min	Air	720	3 hr

Test results

The results of the present investigation are shown in Fig. 2, where the amount of relaxation after 20 hours is plotted against temperature as a percentage of the initial torque.

Since the materials were largely plastified at all test temperatures, the formula:

$$\tau_r = \frac{12T_r}{\pi d^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where τ = residual stress
T_r = residual torque
d = specimen dia. = 10 mm

valid in the plastic range, may be used with fair accuracy if derivation of residual stress from such plots is desired.

Remarks

Disregarding the value of relief (that, for each steel is determined by its particular composition and structure), and taking into consideration the features of the curves in Fig. 2, two points are immediately obvious:

(1) In the high temperature range (600–750°C.) all curves behave in the same way, *i.e.*, they exhibit an asymptotical trend towards 100% relief.
(2) In the low temperature range (450–600°C.) a quite different behaviour is observed between low Cr– low Mo (*A* & *B*) and medium or high Cr steels (*C* & *D*). Starting from 450°C., the former steels show at first a very slight increase of the relaxation amount, the curve becoming abruptly steep in the 550–600°C. range. Thus the whole

curve takes on a characteristic S shape. For the latter steels, on the other hand, the slope of the curve continuously decreases as the temperature increases.

Bearing in mind that the amount of relaxation is the result partly of the decrease of elastic limit while temperature is increasing and partly of creep deformation, it has been thought that the explanation of such a feature could perhaps be gained through separate evaluation of these two factors.

Conventional tensile tests at several temperatures were therefore carried out on *B* and *D* steels, whose behaviours show the greatest difference (*see* Fig. 2) The yield point $\sigma_{0\cdot2}$ of these steels is plotted against temperature in Fig. 3. It can be seen that type *B* curve has an almost flat portion between 450° and 600°C. This agrees with the results found by Glen[1] on steels of similar composition and which he and other investigators attributed to precipitation hardening caused by deformation during the test. No similar feature is observed on type *D* steel between 400° and 700°C. This may probably be assumed to be the result of different behaviour of Cr- by comparison with Mo-carbides.

The effect on their relief curves of such a difference between steels *B* and *D* is shown in Fig. 4, where $\tau_s(=0{\cdot}577\,.\,\sigma_{0\cdot2})$ is drawn in comparison with the residual stress τ_r.

As regards steel *B*, it may be seen that between 450° and 550°C. the same precipitation hardening which causes an interruption in the yield point drop also strengthens this steel against creep. Therefore, in this temperature range τ_r appears to be related to τ_s (in fact the ratio τ_r/τ_s is about constant and equal to 0·65).

Over 550°C., owing to the increasingly effective influence of creep, the ratio τ_r/τ_s rapidly decreases.

Thus, we are led to conclude that the S shape of the relief curve for steel *B* (and presumably for all low Cr– low Mo steels) is caused by precipitation hardening taking place around 500°C.

This phenomenon does not occur with steel *D* (or presumably any medium or high Cr steels), the ratio τ_r/τ_s continuously decreasing from 450°C.

Finally we may note that over 600°C. the shape of the relief curves is chiefly due, in all cases, to the progress of creep deformation (as is clearly shown in Fig. 4). Regarding this point, it must be recalled that creep rate is dependent to a great extent upon absolute temperature T according to the relationship: exp. $-Q/(RT)$, where Q is the energy of activation and R is the gas constant. One might thus wonder why the residual stress shows such a slow trend to zero as temperature increases (*see* Fig. 4). The only answer seems to be that the influence of a stress decrease is so effective as to counteract a simultaneous increase of temperature.

A further theoretical explanation may be given if two simplifying hypotheses are accepted. Let us first assume that the stress relief takes place in two different ways during the course of the test: first the stress on the specimen follows the yield point drop during heating and then a further relaxation is caused by creep during holding time. As for the second hypothesis, we shall suppose that a mechanical equation of state is reliable in the range of the very slight deformations involved in the second part of the test, as above defined, though this may not be possible in general.

Some fundamental experiments by Dorn[2] did however prove that creep rate γ obeys the following law, as far as high temperatures and low stresses are concerned:

$$\gamma = S\,.\,\text{exp.}-Q/(RT)\,.\,\tau^n \quad \ldots\ldots\ldots\ldots \quad (4)$$

where S is a parameter dependent on the degree of alteration induced in the metal structure by creep.

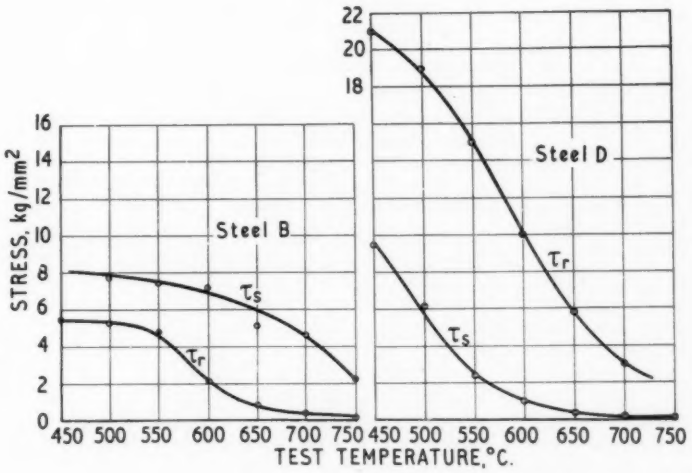
Since a given value of total strain results in different structures, depending on stress, such a parameter does not appear to be related to strain according to a mathematical function. Thus, relation (4) cannot be interpreted as a mechanical equation of state.

However the present conditions, on account of the very small deformations involved, allow us to consider S as a constant.

Then bearing in mind the relaxation relationship:

$$\frac{\tau}{G}+\gamma = \gamma_0 \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

where τ = residual stress
G = shear modulus
γ_0 = initial deformation



4—*Plotting of* $\tau_s=0{\cdot}577\,.\,\sigma_{0\cdot2}$ *and* τ_r *against temperature for* B *and* D *steels*

differentiating *versus* time,

$$\frac{\tau}{G}+\gamma=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

and combining relations (6) and (4), we obtain:

$$S\,.\,\exp.-Q/(RT)\,.\,\tau^n=-\frac{\tau}{G} \quad \ldots\ldots\ldots\ldots \quad (7)$$

From here, through integration:

$$G\,.\,S\,.\,\exp.-Q/(RT)\int_0^t dt=-\int_{\tau_0}^{\tau}\frac{d\tau}{\tau^n} \quad \ldots\ldots\ldots \quad (8)$$

where τ_0 = initial stress
t = testing time

That is:

$$G\,.\,S\,.\,\exp.-Q/(RT)\,.\,t=\frac{1}{n-1}\left(\frac{1}{\tau^{n-1}}-\frac{1}{\tau_0{}^{n-1}}\right) \ldots\ldots \quad (9)$$

Relation (9) allows the calculation of residual stress τ from the values of initial stress τ_0, testing time t and other parameters depending on the material.

Unfortunately, the evaluation of the degree of approximation of this formula would require a knowledge of the exact values for Q, S, G and n at all temperatures, which would involve a great deal of experimental work. In the present case, a rough confirmation has been possible for steel *D*, on which creep tests were previously made at 500° and 553°C., giving $n\simeq 6$ and $Q\simeq 75{,}000$ cal/mole. Such values should be almost independent of temperature.

A curve similar to that of Fig. 4 is obtained for $t=20$ hr, if those values are introduced into equation (9), the value of τ_s being considered as the initial stress τ_0 at each temperature and assuming for $G\,.\,S$ a convenient figure.

The results of these calculations are not reported in detail because it is not felt they can constitute a satisfactory confirmation for equation (9), owing to the lack of exact values for all parameters.

However, the previous considerations have shown that the exponent n in equation (9) may reach such high values as to justify the strong influence of actual stress on the behaviour of relaxation curves.

REFERENCES

1. J. GLEN: "An experimental study of the strength and ductility of steel at elevated temperatures." ASTM Special Technical Publication, No. 128, 1952.
2. J. E. DORN: "Some fundamental experiments on high-temperature creep." Symposium N.P.L., London, 1954.

IIW ANNOUNCEMENTS

Resistance Welding

The Governing Council of the IIW has approved the following recommendation, prepared by Commission III – 'Resistance Welding', which is addressed to the manufacturers of resistance welding machines:

'Manufacturers of spot welding machines should be able, on request, to quote to a customer the number of spot welds which the machine will make per hour, under conditions specified by the manufacturer, without the temperature rise of the transformer exceeding that permitted by the relevant regulations.'

Brittle Fracture Mechanics

At its meeting in April, 1961, Commission IX – 'Behaviour of Metals Subjected to Welding' decided to draw attention to the existence of the following yearly bibliography:

'Researches on Brittle Fracture Mechanics – Progress Report VI – Bibliography' by P. E. Lagasse.

The text of this document can be obtained from the 'Centre National de Recherches Métallurgiques – Abbaye du Val Benoit – Liège (Belgium).

International WELDING

Reports on Fatigue Failures

Fatigue phenomena may affect welded as well as other constructions. Consequently, whenever a welded assembly is required to withstand cyclic stresses, those responsible for its manufacture should ensure that the appropriate measures, analogous to those considered indispensable in non-welded products, are taken.

Among the great variety of types of assembly made possible by welding, may be some of equivalent static strength in service but which behave very differently under fatigue loading. Although further progress in this field may still be made, it is now known which of these types of assembly are to be recommended and which to be avoided. Commission XIII (Fatigue Testing) of the International Institute of Welding has collected critical reports on fatigue failures occurring in service in welded constructions in order that relevant information on this subject may be placed at the disposal of manufacturers. Some of these reports have been circulated for publication, following the Madrid meetings in 1956, the Essen meetings in 1957, the Vienna meetings in 1958, and the Opatija meetings in 1959. At its Liège meetings in June 1960, the Commission recommended the reports attached for publication.

These reports are all presented in the same form corresponding, in so far as possible, to the questions in the inquiry circulated by the Commission with a view to obtaining the information which it wished to assemble. No information is given concerning the origin or author of these reports since the information was collected on the understanding that it would be considered as having been supplied anonymously and the Commission has acted on this understanding.*

FRACTURE OF A DIESEL ENGINE CONNECTING-ROD

1. Type of construction in which failure occurred and nature of stresses

The connecting-rod was from the diesel engine of a small North Sea fishing-boat. The rod was put into service in 1939 and since then had never needed any repair. The fracture took place in 1959, after 20 years of normal service.

2. Information concerning the fracture

Fig. 1 shows that the fracture is of the fatigue type; the point of initiation is indicated by the arrow.

Examination of the surface in the region of fracture initiation shows a weld seam along the whole length of the rod. The fatigue crack started in the middle of this weld seam (Fig. 2) which is assumed to date from the time of manufacture of the rod.

After the broken face had been polished a weld defect (slag inclusion) could be seen just at the initiation point (Fig. 3: the inclusion is indicated by an arrow).

3. Presumed causes of the failure

The welding was successful from the point of view of resistance to brittle fracture, but the presence of a slag inclusion led to fatigue fracture after 20 years' service. The surface of the fracture was very smooth and indicates the application of very numerous stress cycles slightly exceeding the fatigue limit. It is, however, out of the question that these stresses could have been only those occurring during normal service in the engine since, in that case, the rod would have been

**International Welding*, 1961, No. 1, p. 16s.

Report IIS/IIW–67–61 prepared by Commission XIII "Fatigue Testing" of the International Institute of Welding, but not committing the IIW as a whole. 642a

Fig. 1.

fractured in a much shorter period than 20 years. The stresses responsible for the fracture must be looked for in the range of stress resulting from periods of abnormal operation of the engine, such as momentary overloading, irregularities of a mechanical nature etc.

In regard to this accident, it should be remembered that, in principle, the repair of the connecting-rod should have been successful. A very slight weld defect

Fig. 3.

combined with abnormal working conditions were necessary to bring about failure.

The weld defect would today easily have been detected by ultrasonic examination. In this connection

Fig. 2.

it can be said that, in view of the slightness of the defect, it might be considered tolerable in many welded constructions.

In this case, however, the component had not been designed for welded fabrication but had been repaired by welding; in these circumstances no defect would seem admissible.

FRACTURE OF A WEB OF A CRANK-SHAFT REPAIRED BY WELDING

1. Type of construction in which failure occurred

The fracture occurred in the crank-shaft of a diesel engine of 3250 h.p., forming part of the propulsion machinery of a tanker.

This crank-shaft was made up of two lengths connected by flanges each having three built-up crank throws. Each crank throw consisted of two webs of cast steel, hot-shrunk on to the crank-pins (Fig. 1).

2. Stresses during normal operation in the region where the failure occurred

2.1—The crank transmitted a torsion moment and therefore its webs sustained bending moments about axes parallel to the crank-pin axes. Moreover these bending moments were not constant but underwent cyclic variations. The same applied to the bending moments about the same axis arising from the action of the connecting-rod on the crank.

2.2—The amplitude of the resultant cyclic stress was not measured. The normal working speed of the engine was 118 revs/min.

3. Information concerning the fracture and the circumstances of its appearance

3.1—The damage, which took place when the ship was at sea, consisted of fracture of a crank web; the engine had then been working for 1649 days.

3.2—The fracture occurred in the web forward of crank 3. Initially located near the transverse plane of symmetry of the web, the fracture propagated later on at a slight angle to this plane and ran into the connection with the main journal.

2—*Path of principal fracture and seepage of oil from the secondary fracture* ×0·4

On the same web, 245 mm from the fracture, another fairly well developed crack existed, the path of which, brought out by a seepage of oil, was roughly parallel to the principal fracture.

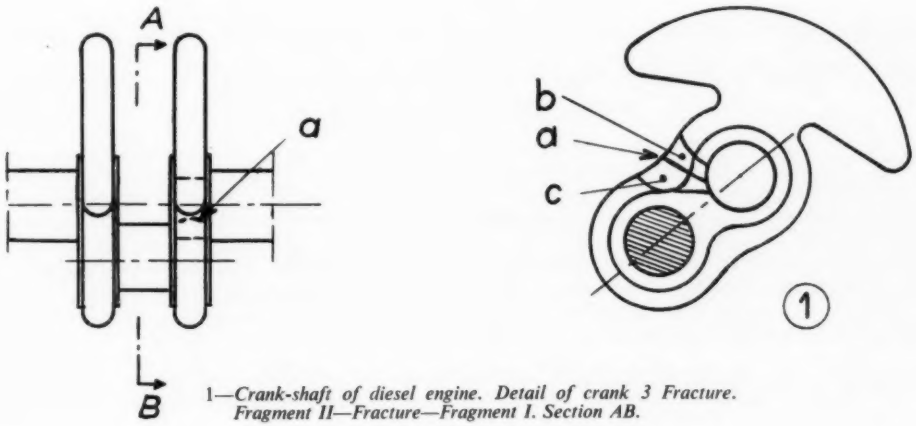
It was also observed that the rough cast surface contained numerous defects having the appearance of fairly large blow-holes. (Fig. 2).

3.3—The principal fracture occupied a section totalling about 280 × 400 mm.

In general the texture is characteristic of progressive cracking under cyclic stress; this texture becomes continually coarser towards the connection of the journal (Fig. 3). The whole of this zone contains a network, frequently extremely dense, of striations.

3.4—Near the outer surface, on the other hand, two regions stand out in marked relief: one, blackish, is surrounded by a zone of fine texture, while the other,

Report IIS/IIW-68-61 of Commission XIII "Fatigue Testing" of the International Institute of Welding. 642b



1—*Crank-shaft of diesel engine. Detail of crank 3 Fracture. Fragment II—Fracture—Fragment I. Section AB.*

3—*General view of surface of the principal fracture. Fragment II* ×0·4

4—*Fragment I. Etched with iodine. View slightly to right* ×0·4

lighter in colour, is concave in form with the radiating relief characteristic of semi-brittle fractures.

The concave zone with radiating relief constituted, judging from the arrangement of striations, the initiation point of the progressive cracking: the blackish area, corresponding to a pre-existing defect, had only been traversed by the fracture.

3.5—The accident was apparently not accompanied by any abnormal circumstances.

4. Nature of materials in the region where the failure occurred

4.1—The webs were made of semi-mild cast carbon steel, having a tensile strength of the order of 30 tons/sq.in. (48 kg/mm²) and satisfactory notch toughness (K=8·3 kg/cm² at 23°C. on a standard French test-piece).

4.2—The pre-existing defect observed in the fracture (*cf.* Figs. 3 and 4) was a solidification crack, defect no. 3221 of the Album of Foundry Defects of the International Commission on Foundry Defects. It was located in the vicinity of the foundry joint plane, as were also the other defects visible on the outer surface (*cf.* Figs. 3 and 2).

4.3—Etching with iodine (Fig. 4) showed that several of these defects had been repaired by welding and that cracks like the concave crack above, at which the fracture began, are in distinct geometric relation to these repairs.

5. Welding conditions

The conditions under which welding was carried out are not known.

In most cases the repairs consisted of small plug welds, obviously made in relatively difficult conditions in view of the large bulk of the piece to be repaired.

6. Presumed causes of the failure and lessons to be drawn from it

The fracture and cracks observed were initiated from cracks of a semi-brittle nature, traceable back to the fabrication of the crank-shaft. These cracks themselves were the result of the repair of local defects by plug welds.

SUMMARY OF ELEVEN CASES OF FATIGUE FRACTURES IN SHAFTS RECLAIMED BY WELDING OR CONTAINING WELDED ATTACHMENTS

The IIW has issued for publication Document IIS/IIW-47-61, but, owing to the impossibility of reproducing the illustrations, we regret we are unable to publish it. It provides particulars, in the form of a summarised table, of eleven cases of fatigue fracture in shafts reclaimed by welding or containing welded attachments. Details are given of each construction, the type of stress in normal service, the material and the welding. The location and details of fracture are illustrated and, in each case, the presumed cause of failure is stated. This document is available on loan from the Library of the Institute.

INTERNATIONAL INSTITUTE OF WELDING

Recommended Practice for the X-Ray Inspection of Fusion Welded Joints

ON ALUMINIUM AND ITS ALLOYS AND MAGNESIUM AND ITS ALLOYS UP TO 2 INCHES (50 mm) THICK

Introduction

In the same way as it appeared desirable to publish recommendations for the radiographic inspection of fusion welded joints on steel, it has been thought worthwhile also to prepare similar recommendations for the inspection of fusion welded joints on aluminium and its alloys and on magnesium and its alloys.

The recommendations do not lay down radiographic standards of acceptance for the joints, but are concerned only with the radiographic technique to be used.

They relate to the inspection of fusion welded butt joints in aluminium and its alloys and in magnesium and its alloys with thicknesses up to 2 inches (50 mm). They are based on the radiographic techniques which have been or are being used with success in industry to inspect welds on light alloys.

In the present text, the inspection techniques are divided into the following two classes:

Class *A*– A general technique for the X-ray inspection of welds on light alloys

Class *B*—A more sensitive technique intended for use where the class *A* technique is unlikely to reveal the defects sought.

Most cases are covered by the correct use of the specifications given for Class *A*.

Class *B* is intended for more important and difficult cases requiring a greater degree of sensitivity. It is generally more expensive and requires longer exposure times.

General

1. Protection

Exposure of any part of the human body to X-rays can be highly injurious. It is therefore essential that, wherever X-ray equipment is in use, adequate precautions should be taken to protect the radiographer and any other person in the vicinity.

Safety precautions against X- and gamma-radiations are specified in the "Recommendations of the International Commission on Radiological Protection", 1955, London. In most countries official recommendations exist. These are in the main based on the recommendations of the International Commission.

2. Surface preparation

Generally speaking, it is most necessary to prepare the surface before taking radiographs, but surface irregularities should be removed where they may cause difficulty in detecting defects within the weld.

It is always advisable to remove surface defects before taking radiographs.

3. Location of the weld on the radiograph

Markers, usually in the form of lead arrows or other symbols, should be placed along both sides of the weld so that its position can be identified on the radiograph. This may not be necessary if the reinforcement is retained.

4. Identification of radiographs

Lead letters should be affixed to each section of the weld being radiographed. The images of these letters should appear on the radiograph to ensure unequivocal identification of the section.

5. Marking

In general, permanent marking by stamping the work piece will provide reference points for the accurate relocation of the position of each radiograph. Where the nature of the material and its service conditions render stamping undesirable, other suitable means for relocating the radiographs must be sought. These include paint marks and accurate sketches.

6. Overlap of films

In radiographing a continuous length of welds, the separate radiographs should overlap sufficiently to ensure that no portion of this length remains unexamined.

7. Image Quality Indicators (I.Q.I.)*

An Image Quality Indicator of a type agreed between the contracting parties should be placed at one or both ends of every section radiographed. It should be placed on the surface facing the source of radiation and, depending on its type, adjacent to or across the weld. Only where this surface is inaccessible should the Image Quality Indicator be placed on the film side; in that case its position should be mentioned in the

Report IIS/IIW-35-59 (ex doc. V-115-59) prepared by Commission V "Testing, Measurement and Control of Welds" of the International Institute of Welding, but not committing the IIW as a whole.

* The term *penetrameter* is habitually used in certain countries in this sense, but the expression *Image Quality Indicator* is now the internationally accepted term.

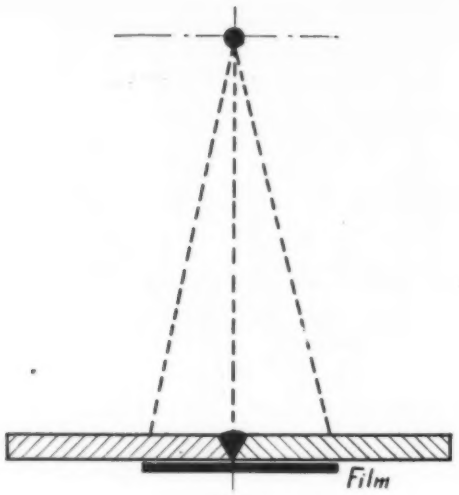


Fig. 1

report as the I.Q.I. indication has not then the same meaning. For details about I.Q.I. see section III.

The minimum sensitivity values required from the I.Q.I. should be agreed between the contracting parties. These values merely provide a guide to the quality of the technique used and do not necessarily bear any direct relation to sensitivity as regards the detection of faults in the weld.

Recommended Techniques for Taking Radiographs

1. Relative positions of the film and source of radiation

Depending on the circumstances and the accessibility of the work pieces, one of the following methods should be used:

1.1—*Planar work pieces*

There is no difficulty in this case; the under side of the work piece being always accessible, the method illustrated in Fig. 1 can be used.

1.2—*Revolving work pieces (longitudinal and transverse welds)*

1.2.1—*Film inside, source outside (Fig. 2)*

The X-ray source is placed outside, the axis of the beam being perpendicular to the tangent of the circumference at the point where the axis strikes the work piece.

The film is placed inside against the surface, its centre corresponding with the axis of the beam of radiation.

This technique should only be used for hollow bodies sufficiently large to allow the film being placed correctly and only where the conditions laid down in paragraph 7 below can be respected.

1.2.2—*Film outside, source inside (Fig. 3)*

The X-ray source is placed inside and, in the case of transverse welds, preferably with the focus situated in the centre of the hollow body. The film is outside, its centre corresponding with the axis of the X-ray beam.

This technique, when applicable, gives the best results for circular welds on hollow cylindrical bodies, because the different parts of the film are situated at the same distance from the source, thus enabling uniform density to be obtained. However, for this technique, it is necessary either to use special equipment (a tube with a long anode), or to have a work piece of sufficient diameter to enable the lamp to be placed inside it.

1.2.3—*Film and source outside (Figs. 4 & 5)*

The source is placed outside, and for transverse welds, the axis of the beam is inclined with respect to the surface containing the weld. Depending on the source-film distance chosen and the dimensions of the hollow body, it is possible to obtain with this technique, used for circular welds, either two images (Fig. 4) or a single image (Fig. 5).

The film must always be placed on the surface opposite to that facing the source of radiation.

This method should only be used for cylindrical bodies, the interior of which is inaccessible and whose diameter does not exceed 3 to 4 inches (75–100 mm) using the technique illustrated in Fig. 4, and 4–27 inches (100–900 mm) using that illustrated in Fig. 5. Above these values, the source-to-film distance becomes too great.

(*Note*—With regard to the method described in paragraph 1.2.3, in order to eliminate possible interference when a backing ring has been used and to provide the best possibility of fine cracks in the first run being revealed, it is suggested that the beam should be normal to the weld, not inclined, and centred in the plane of the weld).

2. Films and screens*

The films used should be of the non-screen type and

* The definitions of the type of recommended films (non-screen and screen type, fine grain, high contrast, etc.) are related to the conventional descriptions of sensitive material. The figures for thickness of lead screens are only intended for guidance.

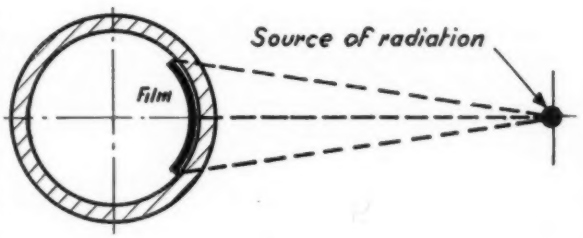


Fig. 2

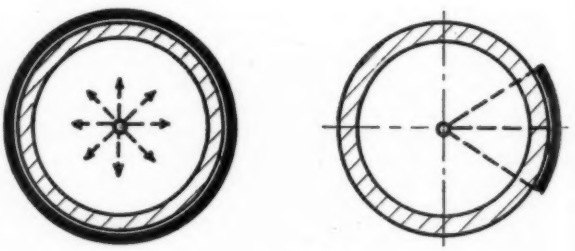


Fig. 3

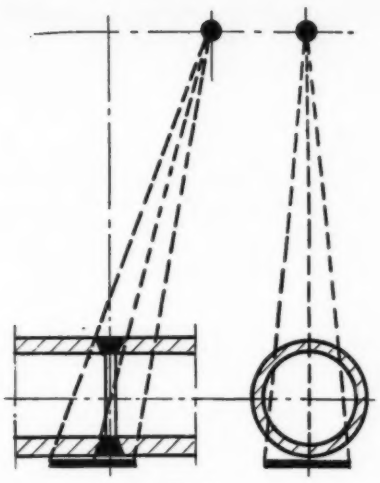


Fig. 4

should meet the following conditions:

Class *A*—medium grain films
Class *B*—fine grain high contrast films.

In general, it is not necessary to use reinforcing screens except where it is desired to reduce the effects of diffused radiation. Lead screens should then be used. These screens should be of thicknesses from 0·1 mm (0·004 inch) for the front screen and 0·15 mm (0·006 inch) for the back screen.

With voltages above 100 kV the exposure time can be slightly reduced by using only a lead back screen or by using also a very thin front screen (0·02 mm or 0·001 inch).

3. Cassettes

For small thicknesses, when the absorption of the faces of the cassette is likely to be too great, the film should be used in its paper envelope or, preferably, in an envelope which will not give a double image.

When cassettes, whether metallic or not, are used, preliminary tests should be carried out to check whether the faces do not result in a decrease in sensitivity for the thickness examined.

When lead screens are used rigid cassettes are preferable to ensure a satisfactory film–screen contact. Flexible cassettes may however be used, provided that precautions are taken to ensure good film–screen contact.

With curved surfaces, in view of the general difficulty of procuring rigid cassettes with the desired curvature, it is preferable to use flexible cassettes.

4. Focus–film distance

The focus–film distance depends on the dimensions d of the focal spot, the film–work-piece distance b* and the acceptable geometric unsharpness U.

These three factors are related by the expression

$$f=\frac{b\,d}{U}\dagger$$

The film–work-piece distance b should be as small as possible, the film being maintained in close contact with the surface. In these conditions, the distance b is practically identical with the thickness of the weld being inspected.

However, in the case of the techinque described in paragraph 1.2.3 which leads to the formation of two images, the distance b in the formula should be the exterior diameter of the tube and not the wall thickness.

The minimum focus–film distance f min. should be determined on the basis of a value of 0·005 inch (0·12 mm) for the geometric unsharpness U in the case of classes A and B.

5. Alignment of beam

The beam of radiation should be directed to the middle of the section under examination and should be normal to the surface at that point, except when specially seeking defects which it is known are best

* The film–work–piece distance means the distance between the surface directly exposed to radiation and the film.

† This is an approximation for the correct formula $f=\frac{b(d+U)}{U}$

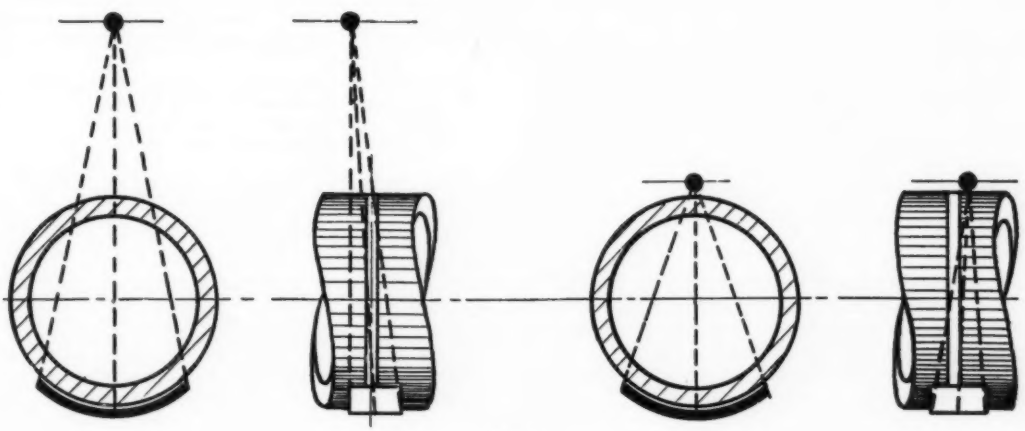


Fig. 5

revealed by a different alignment of the beam; such are defects at a fusion face and the exposure should then be made with the beam directed along the fusion face.

This general rule should be applied with the following two exceptions:

(*a*) When using the double wall double image technique, the inclination of the beam (Fig. 4) should be just sufficient to prevent a super-position of the two images. The inclination of the axis of the beam depends on the diameter and thickness of the cylindrical body and on the width of the welded seams;
(*b*) When using the double wall single image technique, the inclination of the beam (Fig. 5) should be such as to ensure that its axis corresponds with the centre of the section of the weld under examination, in order to prevent any interference with the projection of that part of the welded seam placed nearest the source.

6. Shielding from scattered radiation

Films should be shielded from scattered radiation by an adequate thickness of lead, say 0·05 inch (1·5 mm) or more, placed behind the film–screen combination. Because of the radiation reflected back from the lead itself, a tin sheet about 1 mm thick, or preferably a tin and a copper sheet, each 1 mm thick, may be inserted between the lead plate and the film–screen combination.

In addition, in order to reduce the effect of radiation scattered by the work piece, adequate masking should be provided so as to limit the area irradiated to the section under examination.

7. Size of the area examined

The maximum area to be taken into consideration at each exposure should be such that the thickness of the material at the extremities of the exposed area, measured in the direction of the beam, does not lead on the film to density values beyond the admissible limits laid down in paragraph 8.

8. Density of the radiograph

Exposure conditions should be such that the density of the radiograph of the sound weld metal in the area under examination, taking account of fog density, lies within the range:

Class *A*—1·5–2·5.
Class *B*—2·0–3·0.

To avoid unduly high fog densities arising from ageing of the film, development time or temperature, the fog density should be checked from time to time on an unexposed sample taken from the films used and handled and processed under the same conditions as the actual radiographs. The maximum fog density should not exceed 0·2.

9. Tube voltage

To increase the contrast the tube voltage must be as low as practicable. As a basis, the kV should be chosen so as to give an appropriate density with an exposure of not less than 15 mA × min. for a target-to-film distance of about 30 inches (760 mm).

Furthermore, to prevent on the the image losses of contrast due to an excessive filtration of the X-ray beam, the thickness of half absorption of the radiation used should never exceed 0·2 times the thickness examined.

10. Processing

Films should be processed in accordance with the recommendations of the film manufacturers. Particular attention should be paid to temperature and developing time. The radiograph should be free from imperfections due to processing or other causes which could interfere with interpretation.

11. Viewing

The radiographs should be examined in a darkened room on an illuminated diffusing screen, the illuminated area of which should be masked to the minimum required for viewing the radiographic image. The brightness of the screen should preferably be adjustable so as to allow satisfactory reading of the radiographs.

12. Availability of technical data

For each radiograph or set of radiographs, information should be available of the radiographic technique used (type of X-ray equipment, type of film and screen, focus (source)-to-film distance, voltage, tube current, exposure time, marking system) and on any other special circumstances which would allow a better understanding of the results.

Image Quality Indicators

In order to provide an objective check on the correctness of the technique used in making a radiograph (which would affect the sensitivity of the test), it is usual to record on each radiograph the image of an Image Quality Indicator. This device, made of the same material as that under examination, or of a material with comparable absorption,* is placed on the side of the specimen facing the source of radiation. The figures calculated from the image of the I.Q.I. should be considered only as giving an indication of the sentitivity obtained; they bear no direct relationship to the size of the minimum weld defect likely to be revealed by the radiograph. Although various types of I.Q.I. are currently in use, the IIW recommends† that in future these types should be restricted to two:

(*a*) wire type with diameters in geometrical progression
(*b*) step-wedge type, each hole having a diameter equal to the thickness of the corresponding wedge, the dimensions being in geometrical progression.

These types having been successfully used for the inspection of welds on steel, it should also be possible to use them for welds on light alloys.

* These conditions are particularly important in the case of light alloys because of the differences of absorption which may result from the addition of even small amounts to heavier elements.
† See document IIS–IIW–6–58 (ex doc. V–6–57) "Recommended Practice for Radiographic Inspection of Fusion Welded Joints for steel plates up to 2 inches (50 mm)".

INTERNATIONAL INSTITUTE OF WELDING

Reports of Commissions – 1961

Chairmen's reports of the activities of Commissions of IIW following the Annual Assembly held in New York from 12th to 15th April, 1961.

Commission II: ARC WELDING

(*Chairman—Prof. H. E. Jaeger*—Netherlands)

Since the 1960 Annual Assembly which was held in Liège (Belgium), the work of the Commission has been continued at various Sub-commission meetings held at the dates and places shown below:

Sub-commission A (Effect of hydrogen in weld metal) 8 September 1960 in Copenhagen
Sub-commission B (Testing and measurement of arc welding equipment) 19 January 1961 in Paris
Sub-commission C (Testing and measurement of weld metal) 9 September 1960 in Copenhagen
Sub-commission D (Deep penetration welding) 9 September 1960 in Copenhagen
Sub-commission E (Classification of electrodes) 7 September 1960 in Copenhagen

The meetings of Commission II during the New York Assembly were attended by 14 delegates, 21 experts and 21 observers, totalling 56 persons from 18 countries.

The 45 documents studied fall into the following categories:

3 general documents
5 Sub-commission A documents
7 Sub-commission B documents
7 Sub-commission C documents
13 Sub-commission D documents
10 Sub-commission E documents.

I. GENERAL

At the previous annual meeting of Commission Chairmen, it was suggested that the following welding processes, namely:

(1) Metal-arc welding with stationary covered electrode (or fire-cracker welding)
(2) Metal-arc welding with continuous bare electrode (without gas shielding)
(3) Metal-arc welding with continuous covered electrode

should, from now on, fall within the terms of reference of Commission II instead of those of Commission XII (Special arc welding processes). This means that these processes, whether manual, semi-automatic or automatic, will form part of the work of Commission II. A resolution in this connection was approved by the Governing Council. The field of activity of Commission II will, therefore, include all the items mentioned in that resolution.

At the request of the Chairman, Professor Rykalin (U.S.S.R.) put forward his ideas on the introduction of research on arc physics into the work of the IIW. As this matter had been previously examined by the Chairman, the Commission agreed to the establishment of a special Working Group under the auspices of the IIW, namely "Working Group 212", so as to indicate that this Group concerns both Commissions II and XII. This group is to be launched, with the co-operation of the IIW secretariats, at a meeting to be held probably towards the end of 1961. The Governing Council has agreed to this.

II. SUB-COMMISSION A—EFFECT OF HYDROGEN IN WELD METAL

(*Chairman—Dr. N. Christensen*—Norway)

1. The main points arising out of the annual report of the Sub-commission (Doc. II–173–61) are:

1.1 Methods for defining "H" electrodes

The nine months between the Liège and New York Assemblies proved too short a space of time in which to obtain definite results. More comprehensive information must be made available and although the work of the Sub-commission is progressing well, other investigations must be made with a view to defining various methods which take into account the different types of electrode and their applications. Underbead cracking tests will be carried out jointly with Sub-commission B (Weldability in relation to transformation characteristics) of Commission IX (Behaviour of metals subjected to welding) with samples from the same plate.

1.2 Temporary deterioration of mechanical properties of weld metal due to hydrogen

A report by the French delegation, entitled "Influence de l'hydrogène, de l'écrouissage et du vieillissement sur la résilience de l'acier extra doux" (Influence of hydrogen, cold-working and ageing on the impact value (U notch) of extra mild steel) (Doc. IIA–73–61) will be studied by the Sub-commission.

1.3 Effect of heat treatment at 250°C. on the hydrogen content of weld metal

A report by the American delegates will be submitted shortly to the members of the Sub-commission.

2. Other work

It was decided that further information on the IIW method for determining the total hydrogen content would be submitted by the Sub-commission Chairman at the next Annual Assembly in Oslo.

III. SUB-COMMISSION B—TESTING AND MEASUREMENT OF WELDING EQUIPMENT

(*Chairman—A. Gaubert*—France)

The main points arising from the annual report of Sub-commission B (Doc. II–212–61) are:

1. Definition of the suitability for welding of different equipment

1.1 The object of the experiments was to determine the coefficients r and ρ* on the basis of the re-establishment of voltage, after short-circuit, by a potential provided by a rectifier and a battery of accumulators. These experiments were started last year and showed the necessity for studying the variation of the coefficients r and ρ in terms of the short-circuit time. The following two programmes were made possible by the use of the new rotary switch designed by Mr. Besson (Switzerland).

Programme 1
Time on load from 0·23 to 0·25 sec.
Time on short-circuit varied between 0 and 0·027 sec.
Programme 2
Time on load from 0·23 to 0·29 sec.
Short-circuit varied between 0 and 0·027 sec.
Open circuit from 0·23 to 0·25 sec.

The second programme is especially interesting for the study of the re-establishment of voltage. When the switch was put into operation, the important part played by the contact resistance of the brushes, which must be kept as low as possible, was shown. A new rotary switch improved in this respect is now being constructed. The experiments were carried out using the eight generators which were studied previously and for which, therefore, information exists concerning firstly, the value of r and ρ and, secondly, the subjective opinion of welders working with a welding current of 115 amp. The results were obtained for current settings of 80, 120 and 160 amp.

1.3 The following conclusions were reached:

(a) Except for the generators for which the coefficients r and ρ are near to 1, the values determined by means of the above equipment are a decreasing function of the short-circuit time.

(b) For the settings corresponding to an output of about 120 amp, which is the only output allowing direct comparison with the results obtained in previous tests, a short-circuit duration between 0·015 and 0·025 sec. must be achieved for the values of the coefficients r and ρ to be close to those obtained by droplet transfer.

(c) Except for machines 3 and 7, both of the cross field type, the values of the coefficients r and ρ determined by the switch method are slightly higher than those obtained by droplet transfer.

* For the definition of the coefficients r and ρ refer to previous reports.

1.4 Mr. Bertung (Denmark) Doc. IIB–83–60 "Proposition pour un jugement de l'aptitude d'un appareil de soudage à maintenir un arc stable" (Proposal for assessing the ability of a welding machine to maintain a stable arc), showed that by an analytical expression comprising an exponential function, it is possible to represent the variation of the current as a function of time when changed from working under an established load to short-circuit. These observations show the necessity for subdivising the range of regulation of equipment into divisions inside which the coefficients may be determined.

The above-mentioned automatic switch, coupled for carrying out programme 2, made it possible to study the dynamic voltage *Ud* as a function of the short-circuit duration. The eight generators previously mentioned have been tested. The results obtained led to the following conclusions:

(a) Generally speaking, *Ud* decreases when t increases. For a current of 120 amp, however, and for certain types of generators, the variation is negligible and even showed, for short-circuit durations above 0·015 sec, a change to the opposite direction.

(b) If a restriction is made to the value $t=0{\cdot}015$ sec, a good correlation is obtained between the values of r and *Ud* and the subjective classification. The classification established from the values of *Ud* gives in particular a better realisation of the ease of operation already noted with the no. 3 generator which is of the self-excited type.

1.5 To verify a hypothesis according to which the oscillations of current and power leading to the expression of the coefficients r and ρ are, to a large extent, attributable to arc phenomena and, consequently, of little significance *vis-à-vis* the generators Messrs. Kocher and Mayer (Switzerland) (see Doc. IIB–84–60 "Observations relatives aux critères ρ et r'') (Observations relating to the criteria ρ and r), have embarked on a long series of experiments in this connection; the conclusions of this work support the thesis summarised above. A critical analysis of the various oscillograms obtained has shown that, in every case, neither the absence of a sudden short-circuit break nor too high a resistance of the load are exactly compatible with the conditions necessary to obtain the correct values of r and ρ; the conclusions drawn by Messrs. Kocher and Mayer could not therefore be accepted.

However, these experiments, which can be interpreted in terms of the work done previously by Messrs. Carrer and Girardi (Italy), merit mention in this report.

1.6 Since the publication of Document IIS/IIW–11–58 (ex Doc. II–31–58) "Dynamic behaviour of DC arc welding generators—Proposal for a definition of suitability for welding" by Prof. Carrer (Italy), a large volume of experimental work has been produced and it seems an opportune moment to make known the main conclusions drawn from these studies, especially in connection with the latest improvements to be made to the automatic switch. Messrs. Besson and Carrer were therefore asked, and have subsequently agreed, to prepare a document to be submitted for study by Commission II at its next meeting in Oslo.

1.7 With regard to suitability for welding of single-phase transformers, Mr. Bertung has established an

empirical relationship for calculating the minimum no-load voltage, by using circuits consisting of a constant voltage transformer and a transistor making possible variation of the shape coefficient of the current wave.

According to Mr. Besson's first conclusions, it would appear more practical to choose, as a criterion of suitability for welding, the variation of the slope of the current wave, close to its zero value. The work of Mr. Besson (Doc. IIB–90–61 "Note sur l'aptitude au soudage des transformateurs statiques, suite de l'étude rapportée sous l'indice IIB–86–61") (Memorandum on the suitability for welding of static transformers, continuation of the study begun in Document IIB–86–61) will be examined in more detail next year.

A document prepared by Mr. Bjornstad (Norway) (Doc. IIB–87–61 "Suitability for welding of AC arc welding power sources") shows the importance of maintaining, as a criterion of suitability for welding, the shape coefficient of the current wave.

2. Safety in arc welding

The handbook published by the IIW on hygiene and safety (Doc. IIS/IIW–58–60) will be distributed to members of Sub-commission B.

3. Other work

The draft specification of arc welding equipment studied and completed by SC 4 (Arc welding equipment) of ISO/TC 44 (Welding), was to be re-examined by ISO/TC 44 at their meeting in June 1961, in Helsinki.

On an international level, the problems raised connection of welding equipment to the mains have been taken over for study by the Union Internationale des Producteurs et Distributeurs d'Electricité (UNIPEDE) A first report on the connection of resistance welding machines has been tabled.

IV. SUB-COMMISSION C—TESTING AND MEASUREMENT OF WELD METAL

(*Chairman—Dr. U. Girardi*—Italy)

The following matters were dealt with in the annual report of Sub-commission C (Doc. II–199–61):

1. Study of the impact properties of weld metal at temperatures below 0°C.

1.1 A special report on this study (Doc. II–200–61 "Report on the present state of the studies on the method of approval of electrodes for low temperature operation adopting the Charpy V-notch impact tests specimen") was submitted. The points raised during discussion of this document are as follows:

Scientific problems: A new document (Doc. IIC–102–61) was submitted by the Swiss delegation and will be studied next year. Mr. Girardi pointed out that the impact testpieces were taken perpendicularly to the direction of welding, the notch being perpendicular to the surface of the plate and located in the centre of the weld, and also that these testpieces did not only consist of weld metal.

Practical problems: It was confirmed that the report prepared by the United Kingdom delegation, following the proposal from Italy, will be available for the next meeting of Sub-commission C in Helsinki.

There will also be a new proposal from the Dutch delegation based on the sequential analysis method.

2. Method of testing hardness for the code of symbolisation for hardsurfacing electrodes

A special report on the method of testing hardness for the code of symbolisation for hardsurfacing electrodes (Doc. II–198–61) was submitted. Commission II agreed to transmit this document to Sub-commission E so that these investigations could be followed up.

3. Definition and determination of fusion and deposit coefficients Characteristics of covered electrodes

Explanations of the aims of this study and of the choice of acceptable properties were supplied.

Commission II agreed that the study should centre on the following four main properties:

(A) Metal recovery of electrode
(B3) Fusion constant
(B5) Deposit constant
(C) Maximum deposition rate.

V. SUB-COMMISSION D—DEEP PENETRATION WELDING

(*Chairman—J. G. Daivier*—Belgium)

In the absence of Mr. Daivier, Sub-commission D's report of activity (Doc. II–205–61) was presented by Mr. Lefèvre.

1. Code of practice for deep penetration welding

The division of this document into 10 chapters, their titles and the order in which they are presented were approved. The content of each was then examined. The final text of the document may be presented at the next assembly.

2. Study of special electrodes for the execution of the first run without a sealing run

A new document (II–172–61 "Application of URANAMI welding electrode to hull construction") concerning document II–146–60 (Investigation of the practical application of URANAMI (back wave) welding electrodes) was submitted by the Japanese delegation. It will be examined by Sub-commission D. The Japanese delegation was invited to make a summary for publication of these two documents.

VI. SUB-COMMISSION E—CLASSIFICATION OF ELECTRODES

(*Chairman—Dr. E. Kauhausen*—Germany)

In the absence of Mr. Kauhausen, the report of activity of Sub-commission E (Doc. II–193–61) was presented by Mr. A. Mudde.

1. As Mr. Kauhausen had expressed a wish to be relieved of his duties as Chairman, it was decided that he would be succeeded permanently by Mr. Mudde at the next annual meeting in Oslo.

2. Filler products

2.1 At the meeting of SC 3 (Filler metals and electrodes) of ISO/TC 44, in Paris, on 16, 17 and 18 January, 1961, a general plan for coding all filler products was discussed. This project consists of four groups of symbols indicating:

Group I	Nature and form of filler metal, process, flux, gas, etc.
Group II	Chemical composition of deposited metal
Group III	Properties of deposited metal
Group IV	Method of application

2.2 Furthermore, document II–127–60 "Code of symbols for filler products. Electrodes for hardsurfacing" was discussed.

2.3 Document II–194–61 (Proposal for future work on the symbolisation of filler materials on the basis of resolution 58 of ISO/TC 44 SC 3 and IIW document SST–222–59) was discussed and approved. This document will be discussed by the Chairmen of Commissions I, II, VII and XII.

3. Classification and symbolisation of electrodes

3.1 Sub-commission E will study a less complicated system of classification of electrodes, distinct from the symbolisation.

3.2 At the request of SC 3 of ISO/TC 44, Sub-commission E will undertake the task of preparing a code of symbols of electrodes used for welding austenitic steels, heat-resistant steels and alloyed steels.

VII. PROGRAMME OF WORK FOR THE YEAR 1961–62

Commission II and its Sub-commissions will study the following questions:

Sub-commission A

(1) *Methods of defining "H" electrodes with a very low hydrogen content*

(*a*) Moisture content of electrode coverings (for information)

(*b*) Residual water content of electrode coverings

(*c*) Diffusable hydrogen content (ISO method)

(*d*) Total hydrogen content (IIW method)

(*e*) Susceptibility to cracking with a given steel.

(2) *The role of hydrogen in acceptance testing of electrodes*

(*a*) Continuation of studies on the importance of micro-cracking in single-run seams deposited with commercial electrodes (tensile and bend tests).

(*b*) Continued study of the mechanical properties of weld metal specimens deposited with acid and rutile electrodes.

(*c*) Investigations of methods of assessing the extent of micro-cracking in multi-layer seams by comparison with single run seams.

(3) *Temporary deterioration of mechanical properties due to hydrogen*

Discussion of a report from the French delegation (Doc. IIA–73–61 "Influence de l'hydrogène, de l'écrouissage et du vieillissement sur la résilience UF de l'acier extra doux") – ("Influence of hydrogen cold-working and ageing on the impact value (U notch) of extra mild steel"), and of other reports which may be available.

(4) *Non-metallic inclusions in weld metal*

Preparation of complete final report.

(5) *Effect of heat treatment at 250°C. upon the hydrogen content of weld metal*

(*a*) Determination of total hydrogen contents remaining after heat treatment at 250°C. for 16 hours.

(*b*) Discussion of a report to be presented by the U.S.A. delegation and other reports which may be available.

Sub-commission B

(1) *Definition of the suitability for welding of different equipment*

(*a*) Experimental work for the practical determination of the coefficients r and ρ by using a battery of accumulators and rectifiers for the re-establishment of the voltage.

Influence of the duration of short-circuits on the values of the two criteria, when the short-circuit time is above 15 milli-seconds. Continuation of the study begun in 1961 using an improved switch. Possible use of power transistors in order to obtain sudden breaks without arc phenomena.

(*b*) Determination of the dynamic voltage values after a short-circuit of about 15 milli-seconds. Continuation of the study begun in 1961 using the improved switch mentioned above.

(*c*) Summary of the work undertaken by Messrs. Besson, Carrer and Girardi on the dynamic properties of the generators since the publication of document IIW/IIS–11–58 (ex Doc. II–31–58).

(*d*) Comparison of the various criteria proposed for the suitability for welding.

(*e*) Addition to the study on the incidence of the dynamic behaviour of welding generators on the variation of the relative penetration.

(*f*) Supplementary studies on the correlation between the fusion losses and the magnitude of dynamic short-circuit currents. Influence of the phenomena of magnetic arc blow.

(*g*) Study of document II–170–61: "Dynamic characteristic of DC welding generators", by Mr. Masao Kamiya (Japan).

(*h*) Suitability for welding of transformers. Study of documents II–87–61 (work by Mr. Bjornstad) and IIB–90–61 (work by Mr. Besson).

(2) *Measurement of arc welding currents and voltages*

Study of the work carried out by Mr. Bertung.

(3) *Definition and measurement of the flexibility of welding cables*

Application by various investigations of document IIW/IIS–21–59 (ex Doc. II–30–58) "Measurement of the flexibility of welding cables" (Report prepared by Mr. Besson). Study of additional proposals.

(4) *Programme for the specification of flexible welding cables*

(5) *Safety in arc welding*

(*a*) Results of the inquiry on regulations.

(*b*) Liaison to be established with Committee 26 of the International Electrotechnical Commission.

(6) *Liaison with Sub-committee 4 of ISO/TC 44*

Study of German specifications for transformer-rectifiers. Report on the work of ISO/TC 44 concerning welding equipment.

(7) *Problems arising from the connection to the main power supply of single-phase equipment*

Study of document IIB–29–57 (Experimental equipment for the study of flicker; results and measurement on low voltage networks) and, possibly, the work of UNIPEDE.

(8) *Calculation of the power output of multi-operator equipment*

Preparation of tables or charts representing the formulae previously established. (Doc. IIB–58–59 "The possible load of multi-operator welding sources").

Sub-commission C

(1) Establishment of a *conventional* method for acceptance tests for the impact properties of weld metal at low temperatures, ensuring a sufficient degree of reproducibility of the results.

(2) Establishment of a method to determine the efficiency and fusion constant of electrodes, adopting document II–199–61 as a basis for discussion.

(3) Collection of published works and available experimental data on the study of brittle fracture in weld metal and the technological and metallurgical factors which could influence the dispersion and distribution of impact values.

(4) Examination of hot cracking phenomena in mild steel weld metal.

(5) Execution of hot cracking tests in chromium–nickel austenitic weld metal.

Sub-commission D

(1) Completion of the establishment of the code of good practice for deep penetration welding.

(2) Examination of document II–172–61.

(3) Examination of joints welded on one side only.

(4) Preparation of reference charts characterising the appearance of weld seams.

Sub-commission E

(1) Revision of the code for the symbolisation of hardfacing electrodes in accordance with instructions given in document II–198–61 (Method of testing hardness for hardfacing electrodes) and of ISO/TC 44 SC 3.

(2) Discussion of the proposals made by the Italian and Belgian delegations concerning the classification of electrodes for welding mild steels.

(3) Examination of a method of specification and a code of symbol for:

(*a*) electrodes which deposit stainless austenitic steels;

(*b*) electrodes which deposit chromium–molybdenum steels for welding elements subjected to high temperature service conditions;

(*c*) electrodes in currently used alloyed steels;

(*d*) electrodes for welding cast iron.

Commission III: RESISTANCE WELDING

(*Chairman—Dr. H. G. Taylor*—United Kingdom)

Twelve countries were represented by about thirty delegates, experts and observers who attended the four meetings held.

Projection Welding

A report from Japan, Doc. III–138–60: "Movement of Nugget in Multiple Projection Welds" was discussed in some detail. It refers to a phenomenon which has been observed by other investigators but not previously reported. The conditions giving rise to the effect are known and it was decided that an abstract of the report should be prepared by the Japanese and that, at the same time, the U.S.A. delegation should draw up a document explaining how the trouble can be avoided. These two documents are to be submitted for consideration next year with a view to joint publication.

A report, Doc. III–139–60: "Projection Welding of Low Carbon Steel with Embossed Projections" was submitted by the U.S.A. delegation. It dealt in detail with experiments using three kinds of projections, all different from those previously recommended by the I.I.W. The advantages of these differences were explained and attention was drawn to the fact that yet other shapes and sizes were widely used in other countries. It was decided to draw the attention of the British Welding Research Association to these divergencies in practice from I.I.W. recommendations, which were based on B.W.R.A. work, and to suggest that future research should take them into account.

The American Welding Research Council and the French Institute of Welding are also planning research on projection welding and it was decided that information should be exchanged between these parties to minimise overlapping of work or to make comparisons possible.

Classification of Spot Welds

Discussion on this subject was based on Doc. III–121–60 "Preliminary draft classification of spot welds in mild steel" submitted by Sub-commission III E, "Recommendation for classification of spot welded joints in mild steel", but it was clear that there was a wide divergence of opinion. In a previous year the Commission had recommended that only one class of spot weld be approved, but this had been felt to be unrealistic and, as a compromise, the Belgian delegate had suggested that classification be based on assemblies of spot welds, i.e., spot welded joints, rather than on individual spot welds.

Unfortunately the document produced was too much in the nature of a specification for general acceptance—it being considered that a specification for a series of classes would hamper rather than advance the technique of spot welding.

Attention was drawn to the analogy with arc welding where there is recognition of code and non-code applications, and, in referring the document back to the Sub-commission, the Commission drew attention to the virtues of this type of classification.

Series Welding

Discussion took place on a U.S.A. paper, Doc. III–126–60, "Effect of Steel Back up Blocks on Series Spot Welding", on the use of mild steel back-up blocks in place of copper for series spot welding. Such a change would effect a cost economy if it were

practicable and the report showed that this was the case, but that for equivalent results it was necessary to increase the transformer voltage by 10%. In practice, when large numbers of transformers were used, the need for two different types was considered to be a disadvantage which outweighed the saving in cost of material for the back-up blocks.

Hourly Output of Spot Welding Machines

After consideration of this subject for several years, it had become obvious that no practicable modifications of the proposals would make them generally acceptable. The relevant document was, therefore, abandoned in favour of a general statement that manufacturers should be in a position to provide users with such information as would enable them to compare one machine with another and would show whether or not a given machine would enable them to meet their production requirements.

In this connection, the following resolution was forwarded to the Governing Council, which adopted it:

"Commission III proposes to the Governing Council that the IIW makes the following recommendation to resistance welding machine manufacturers:

Manufacturers of spot welding machines should be able, on request, to quote to a customer the number of spot welds which the machine will make per hour, under conditions specified by the manufacturer, without the temperature rise of the transformer exceeding that permitted by the relevant regulations".

Repair of Resistance Welded Assemblies

One of the criticisms sometimes levelled at resistance welding is that if a resistance-welded product is damaged in use it is difficult to repair. To oppose this view it has been decided to prepare a group of papers, applicable to various industries, showing how repairs may be effected. Little progress was made as data are still awaited on railway rolling stock, but new sources of supply of information are to be investigated.

Non-Destructive Inspection of Welds

The Chairman reported the progress made by the Sub-commission, namely that the Italian delegation would produce only specimens in light alloy, whilst mild steel specimens for test would be prepared elsewhere. All these specimens would subsequently be tested non-destructively by various research workers and then later destructively by the French Institute of Welding. A simple specimen, having one dummy weld in a group of five welds, had been provided by the British delegation and tested in the Netherlands and in France. The dummy weld, which, by visual inspection, appeared identical with the others, was detected with complete certainty by ultrasonics.

The U.S.A. delegation reported that a U.S. motor car manufacturer had just commenced ultrasonic testing of chassis spot welds and had achieved 90% success with material greater than 0·06 inch (1·5 mm) thick. Of the remaining 10% the method tended to show good welds as defective rather than to pass defective welds as good ones. For the time being the method was being used in parallel with destructive testing but it was hoped that in a few months it would be possible to dispense with destructive testing.

Other matters

There is considerable interest in the use of welding primers and an interim report was submitted by the Belgian delegation, (Doc. III–150–61 "Etude sur les impressions de soudage" – "Study on welding primers"). In the discussion which followed it was disclosed that three manufacturers of motor car bodies in U.S.A. and Great Britain were agreed that, of the large number of primers which they had tested, they had found none acceptable, from all points of view, which did not contain zinc.

The document which has been in preparation for some time on the flash welding of light alloys is nearing completion. An interesting report was received from Japan, (Doc. III–137–60) on the flash welding of segregated steel strip for continuous rolling.

Professor Rykalin (U.S.S.R.) summarised a report, (Doc. III–140–60, "Calculation of the heating and cooling in resistance butt welding"), on the heating and cooling of rods in flash welding, and showed that theoretical predictions corresponded closely with practical results.

The Commission accepted responsibility for arc welding by condenser discharge and for welding by ultrasonics with resistance heating—a method analagous to ultrasonic welding. It also decided to discuss at a future meeting the spot welding of galvanised sheets, in which there is considerable interest in the motor car industry. A report was promised by the French delegation.

Commission IV: DOCUMENTATION

(*Chairman—L. Blosset*—France)

At the Annual Assembly of the IIW in New York, nine delegates and experts representing eight countries took part in the work of Commission IV.

I. BIBLIOGRAPHICAL BULLETIN FOR WELDING

The Bibliographical Bulletin for Welding has, as in the past, been produced as a result of the permanent collaboration of the French publisher and of the periodic contributions of certain members of the Commission. The Chairman's general report for 1960–61 (Doc. IV–121–61), gave a comprehensive account of the work carried out in connection with the Bulletin since the Liège Assembly in 1960; this report was approved by the Commission during the New York meetings.

1. Preparation of the Bulletin

The delegations from the following countries prepared bibliographical abstracts of the publications of their countries in 1960: Austria, Czechoslovakia, France, Italy, Japan, Netherlands, Norway, and Sweden. Furthermore, Belgium, Germany, Spain, the United Kingdom, the U.S.A. and Yugoslavia have also made partial contributions. Finally, in addition to abstracts of IIW documents not yet published, France prepared all or part of the abstracts of the technical publications of the following countries: Australia, Belgium (80%), Canada, Denmark, Germany (80%), South Africa, the United Kingdom (about half), U.S.A. ($\frac{3}{4}$) and the U.S.S.R.

For the year 1960, 2,496 abstracts were published in the Bulletin. These abstracts were of publications of the following countries:

	(1)	(2)
Australia	76	—
Austria	37	37
Belgium	97	19
Canada	77	—
Czechoslovakia	102	77
Denmark	6	—
France	285	1781
Germany	359	67
Italy	48	44
Japan	49	45
Netherlands	84	73
Norway	11	10
South Africa	22	—
Spain	27	18
Sweden	63	63
United Kingdom	186	96
U.S.A.	456	117
U.S.S.R.	265	—
Yugoslavia	85	49
IIW	161	—
	2496	2496

Column (1) gives the number of abstracts of publications of each country which appeared in the Bulletin. The number of abstracts prepared by each country is shown in column (2).

The total number of abstracts appearing in the Bulletin in 1960 is slightly higher than that of previous years.

The French organisations were, as usual, responsible for the translation of abstracts from English into French and vice versa and for the bilingual publication of the Bulletin which includes, in the last number, an index of authors.

2. Publication of the Concordance between the Classification System of the IIW and the Universal Decimal Classification System

This document (ex Doc. IV–93–59), recommended by the Governing Council of the IIW in 1959 for publication, has been printed this year by the International Federation of Documentation in The Hague on behalf of the IIW. It was put on sale by the publisher of the Bibliographical Bulletin for Welding, following an earlier inquiry regarding the probable demand.

3. Additions of new headings in the IIW's Classification Table of Documentation

Two working documents, submitted by the Chairman, were discussed by the Commission:

"Liste des éléments susceptibles de présenter un intérêt du point de vue du soudage"
(List of materials which may be of interest from the point of view of welding) (Doc. IV–117–61).
"Projet de modifications et adjonctions à la Table de Classement de la Documentation"
(Draft amendments and additions to the classification table of the Documentation) (Doc. IV–118–61).

Furthermore, Mr. Brizard gave a verbal report on "the applications of rare metals", summarised in Doc. IV–127–61, which helped the Commission in selecting metals to be added to the Table, either under a specific heading, or under an alphabetical heading only, with reference to a collective heading, depending on the amount of relevant documentation.

The Commission finally adopted unanimously a list of amendments and additions to the Classification Table; this list will be distributed to readers of the Bibliographical Bulletin; it concerns, firstly certain metals and semi-conductors, and secondly, welding processes (or allied techniques): electron beam welding in vacuum, rotating arc welding, stud welding, plasma arc welding, electro-slag welding, friction welding, cold pressure welding and ultrasonic welding.

4. Reduction in size of the Bibliographical Bulletin

As the Bulletin has been steadily increasing in size and the cost of its publication has risen accordingly, the Commission unanimously decided both for reasons of principle and economy to:

(*a*) refrain from publishing abstracts of a larger number of articles of a purely commercial nature;
(*b*) abridge abstracts as much as possible, except for publications relating to questions of a specially scientific or technical nature and even to cut out summaries of other articles whose titles are sufficiently explicit.

5. Circulation of the Bibliographical Bulletin—Advertising—Budget

Because of the date of the IIW Assembly, it was not possible to calculate the number of subscribers for 1961; there was a slight fall in this number in 1960. In accordance with a decision taken in Liège in 1960, certain members of the Commission have carried out a new method of propaganda for the Bulletin by supplying publishers of reviews (notably welding reviews) or other publications of their country, with the texts of announcements ready in advance. They were drafted on the basis of texts prepared by the Chairman with a view to obtaining new subscriptions and additional pages of advertising (Doc. IV–119–61).

As propaganda for the Bibliographical Bulletin, the Commission proposed in Resolution 3, transmitted by the Governing Council to the Executive Council for necessary action, that each year at the Assembly an issue of the Bulletin be exhibited together with copies of the journals containing articles abstracted in that issue.

The year 1960 closed with a deficit of 30,345·30 NF which was met by the French Institute of Welding. This figure takes account of the subvention of $2,300 granted by UNESCO to the IIW for the Bulletin in 1960, through the Union of International Engineering Associations (UATI). This deficit is considerably higher than that of the previous year, mainly because of the increase in the number of pages of the Bulletin.

The Executive Council of the UATI has granted a subvention of $2,500 to the Bibliographical Bulletin for 1961.

II. ANNUAL EXHIBITIONS OF PUBLICATIONS DEALING WITH WELDING AND ALLIED PROCESSES—CATALOGUES

1. Exhibition in New York of IIW documents recommended for publication

Following Resolution 3 of the Commission, approved by the Governing Council in Liège in 1960, and thanks to the arrangements made by the American

delegation and the two IIW Secretariats, all the documents recommended by the IIW for publication were exhibited during the New York Assembly, in spite of the fact that no general exhibition of publications relating to welding was organised.

2. Catalogue of the Opatija and Liège Exhibitions 1959–60

For these two exhibitions one catalogue only was issued: it was prepared by the Belgian Organising Committee of the Liège Assembly on the basis of elements supplied by the Yugoslavian and Belgian delegations and reviewed by the Chairman of the Commission. This catalogue was completed for presentation at the New York Assembly.

3. Classification of publications by subjects at future exhibitions of publications

Following two suggestions made by the Chairmen of Commissions IV and XIII "Fatigue Testing", which were discussed at the meeting of Commission Chairmen in November 1960, the Chairmen asked Commission IV to study the possibility of highlighting a different subject at each future exhibition of publications on welding, grouping together the relevant works. In Resolution 1, approved by the Governing Council, the Commission proposed that documents be presented at future exhibitions, firstly, as has been done up till now, by country, secondly, in accordance with a theme, the final choice of which is to be left to the host country. The theme will, in principle, be changed at each exhibition.

The following themes have been suggested to the Norwegian delegation for the exhibition at the Oslo Annual Assembly in 1962, in accordance with Resolution 2 of the Commission adopted by the Governing Council at New York:

(*a*) penstocks and high pressure pipelines (subject of public lectures at the 1962 Assembly)
(*b*) design of welded constructions.

In accordance with Resolution 5 of the Commission, also adopted by the Governing Council, in future for each exhibition of publications, a catalogue dealing only with documents relating to the chosen theme will be published, and not a complete catalogue of the exhibition as in previous years.

4. Orders for works and reviews at Exhibitions

The Governing Council approved the proposal of the Commission (Resolution 4) to take orders at exhibitions of publications and to transmit them to the publishers of the works and reviews, so as to encourage them to take part in these exhibitions.

Commission VI: TERMINOLOGY

(*Chairman—F. M. L. van Horenbeeck*—Belgium)

Since the Annual Assembly held in Liège in July 1960, Commission VI has continued work, at two intermediary meetings and at the 1961 Annual Assembly held in New York, on the preparation of the section dealing with resistance welding of the Multilingual Collection of Terms for Welding and Allied Processes.

The annual meeting of Commission VI in New York, at which Professor G. A. Herpol (Belgium) presided, was attended by delegates and experts from 11 countries, whereas the intermediary meetings, which were held respectively in The Hague in October 1960 and in Brighton in February 1961, were attended by delegates and experts from eight countries.

During the New York meeting, Commission VI completed work on the "Resistance Welding" section, which is at present being printed, and which will constitute the fourth section of the Collection.

This section will comprise some 400 terms specific to resistance welding, of which over 200 will be illustrated. These terms appear in the following 18 languages: Czech, Danish, Dutch, English, Finnish, French, German, Italian, Norwegian, Polish, Rumanian, Russian, Serbo-Croat, Slovak, Slovene, Spanish, Swedish, Turkish.

As in the previous sections, the terms will be grouped in a logical order, those for each concept following each other in the various languages; in a second part, they are regrouped in separate alphabetical lists for each of the 18 languages.

The Commission will continue its work with the preparation of a section containing terms specific to oxygen cutting and the other allied cutting processes.

During this year, a supplement to each of the two sections "General Terms" and "Arc Welding", published in 12 languages, has been prepared; each contains the corresponding terms in the following five languages: Czech, Polish, Russian, Slovak, Turkish. These supplements will be published shortly.

Commission VIII: HYGIENE AND SAFETY

(*Chairman—Mr. L. André*—Sweden)

Commission VIII met at New York from 12 to 15 April, 1961, on the occasion of the Annual Assembly of the IIW. Delegates were present from Belgium, Denmark, France Norway, Poland, United Kingdom and United States. In the absence of Messrs. André and Gerhardsson (Sweden), respectively Chairman and Vice-Chirman of the Commission, Dr. Granjon (France) presided at the meetings.

During the year, Sub-commission A, which is responsible for preparation of a general document on health and safety in special arc welding processes, met in Paris on 27 February, 1961.

The main topics dealt with at the New York meetings were as follows:

Health and safety in special arc welding processes;
Revision of the "Handbook on Health and Safety in Welding and Allied Processes";
Welding fumes behind welders' handshields and helmets.

Special Welding Processes

Of the various welding processes, the handbook recently circulated for publication, and to which reference is made further on (Document IIS/IIW–58–60), deals only with gas welding and arc welding with covered electrodes. With a view to the preparation of a similar document on the so-called special processes, Sub-commission A, which was established at Liège, presented a report on its work (Document VIII–112–(12)–61), which contains a draft plan and a skeleton

bibliography of the questions to be studied. For the moment, only gas-shielded arc welding processes (argon, CO_2 or various mixtures) with consumable or non-consumable electrode will be dealt with in this preparatory work. The proposed plan was adopted by the Commission, subject to some additions being made, and some new documents were added to those which had already been assembled. The Commission then divided up the corresponding drafting work, taking into account the necessity for cooperation with Commission XII (Special Arc Welding Processes), the advice of which was sought, in a resolution adopted by the Governing Council, on the draft of the technical introduction to the proposed document and on the difficult question of the ventilation of work-places.

Revision of the Handbook

Immediately after the decision to publish the "Handbook on Health and Safety in Welding and Allied Processes" (Document IIS/IIW–58–60), it was agreed to proceed with its revision, either by amending certain chapters, or by adding new chapters. The Commission spent a large part of its time at the New York meetings on a detailed examination of the text of the Handbook; the comments made were recorded in the minutes of the meeting and will be taken up again when any future edition is in preparation. However, the amendments decided upon by the Commission in respect to the chapter on ventilation were considered to be of sufficient importance to warrant a resolution, which was approved by the Governing Council, recommending that they should be circulated as soon as ever possible. In addition, the Commission proposes to add to the Handbook chapters on metal spraying, brazing and soldering.

Welding fumes

Mr. Laursen (Denmark) presented a report entitled "Investigation into the Fume Concentration in the Welder's Breathing Zone inside the Helmet and Handshield". This report, whose conclusions will be used for the revision of the corresponding chapters of the Handbook, gives experimental data regarding the fume content *inside* welders' handshields and helmets. It points to the advantage of *local* extraction of the fumes by suction, a process which will be the subject of further experiments carried out by the author.

The Commission is keeping on its agenda for the year 1961–62 the three questions dealt with in this report. It will also deal with the protection of the head and skin of welders, with questions relating to the colour of the walls in welding workshops and with the terminology of protective equipment.

Commission X: RESIDUAL STRESSES AND STRESS RELIEVING

(*Chairman—Dr. R. Weck*—United Kingdom)

Stress relieving of alloy steels

The Commission considered once more the document on the Stress Relieving of Alloy Steels which had been prepared by a Working Group under the Chairmanship of Mr. Tummers (Netherlands) "Summary Report on Stress Relaxation Data" (Doc. X–273–61). The document, containing stress relaxation data as a function of time and temperature obtained in torsion tests which were obtained by the collaborative efforts of a number of countries, had been passed to the Scientific and Technical Secretary for publication, in accordance with the resolution adopted at Liège, in 1960. There was considerable support for the memorandum prepared by Dr. Benson (United Kingdom) "Note on Stress Relaxation Testing Methods" (Doc. X–273–61), which will be published as an integral part of the document and in which the author expresses doubts on the usefulness of stress relaxation data obtained by torsion tests. The Commission considered, however, that no serious errors in stress relieving practice would be likely to arise from the use of the torsion test data.

It was agreed that Mr. Bihet (Belgium) should undertake tension relaxation tests on one or two of the steels in order to ascertain the degree of divergence between torsion test and tensile test data.

Nickel steels

The Commission decided to consider at their next meeting the question of stress relieving 9% nickel steel. Although stress relieving of these steels is considered necessary by some codes, the Commission felt that this requirement may be unnecessary and decided to consider the question at their next meeting with a view to making definite recommendations. The American delegates agreed to collect data in the United States and submit these for consideration by the Commission at their next meeting.

Effect of grain size on stress relaxation

The Commission considered a document by Mr. Tummers "Effect of Grain Size on Stress Relaxation" (Doc. X–260–60), from which it was concluded that grain size as such would not influence the degree of stress relief for a given time and temperature.

Stress relieving temperatures for low alloy steels

The Commission decided to draw the attention of Commission XI to Document X–272–61 OE "Stress-relief of low alloy steels at temperatures of 250°C. and higher" by Mr. Tummers which indicates that the requirements of some codes are at variance with experimental data. A resolution to this effect was adopted and noted by the Governing Council.

Effect of residual stresses on stability of compression members—stub-column tests

The Commission appointed a Working Group consisting of Professor Louis (Belgium), Dr. Tall (U.S.A.) and Professor Marincek (Yugoslavia) to prepare for publication as a Class C document a proposal, prepared by the United States delegation, concerning the procedure to be followed in stub-column tests. It has only become clear recently that residual stresses have a pronounced effect on the buckling load of columns and that existing column formulae must be considered suspect since they leave this important factor entirely out of account. It is important that this should receive consideration in all future researches on columns and that as far as possible a unified procedure should be

adopted. The Working Group processing the document will, in accordance with the rules of the IIW regarding Class C documents, circulate this American document to national delegates for comment since this document can be published as an IIW recommendation only after the agreement of all national delegations has been obtained. The Working Group will also consider the possibility of making a recommendation, proposed by Professor Marincek, that a greater research effort on welded columns should be undertaken in the various countries, possibly within the framework of the column programme of the European Convention of Steelworks Constructors.

Measurement of residual stresses

The Commission considered and recommended for publication (Class A) a report by K. Masubuchi (Japan) "Calculation and measurement of residual stresses due to spot heating" (Doc. X–259–60) in the hope that publication might promote wider discussion and might possibly stimulate similar work in other countries. A reliable solution of this problem would assist very considerably in the utilisation of residual stresses introduced by spot heating for the purpose of increasing the fatigue strength, and possibly even the brittle fracture strength, of certain types of welded construction.

The Commission also considered a report by T. Maeda and T. Yada (Japan) "Investigation on the Shrinkage due to Multiple Spot Heating" (Doc. X–268–61), and recommended publication of this report as a Class A document in view of its interest in relation to the method of fairing of plate structures by means of spot heating. The Governing Council approved two resolutions adopted by the Commission concerning the publication of these documents.

Effect of residual stresses on fatigue strength

The Commission considered two reports by Professor Okerblom (U.S.S.R.) "Effect of Residual Stresses on Weldments' Vibration Strength" (Doc. X–239–59), and "Schème de calcul pour l'évaluation de la résistance à la fatigue des éléments soudés compte tenu des contraintes résiduelles et de changement des propriétés du métal de base provoqués par le soudage" (Method of calculation for evaluating the fatigue strength of welded joints, account being taken of the residual stresses and the changes in the properties of the parent metal as a result of welding) (Doc. X–255–60). In the first of these reports experimental results are given which show that for certain types of welded joints—longitudinal weld combined with transverse butt welds and in a particular type of fillet weld—prestressing by means of overloading increases the fatigue strength, whereas stress relieving by heat treatment reduces the fatigue strength. In the second report an attempt is made to exploit the presence of residual stresses for the purpose of increasing permissible stresses.

Effect of residual stresses on brittle fracture

The Commission discussed eleven reports listed in the Appendix, of which eight were submitted by Japan, two by the United Kingdom and one by the United States. This discussion occupied the Commission for the best part of its four meetings and centred on the basic question to what extent residual stresses or exhaustion of ductility—the mechanism proposed by Professor Mylonas (United States)—are responsible for the initiation of brittle fracture at low average stress (low stress brittle fracture). Professor Mylonas, who had already submitted a report at the meeting in Liège which showed that low stress brittle fracture could be produced in unwelded specimens provided the material at the bottom of the notch had previously been severely overstrained in compression—a process Professor Mylonas calls "exhaustion of ductility"—submitted fresh evidence in support of his thesis. The Japanese delegates on the other hand had submitted extensive evidence from which it could be concluded that low stress brittle fracture would not occur in the absence of residual stresses. Although this crucial question was not finally resolved, the elucidation of the problem has been very considerably advanced during this meeting to a stage where it should be possible to devise a series of critical tests to decide this question one way or the other.

Mr. Schnadt (Switzerland) drew attention to the fact that the aspect of straining velocity, which he considered to be of extreme importance, had been neglected in most of the Commission's work up to date. The Commission decided to consider Mr. Schnadt's ideas in detail at the next meeting in Oslo and Mr. Schnadt agreed to make available immediately a document which he had submitted to Commission IX "A new approach to the solution of brittle fracture problems in modern steel construction" (Doc. IX–292–61). Delegates are to study this document and submit their questions and comments in writing well in advance of the meeting at which a whole session is to be devoted to the discussion. Particular emphasis in this discussion will be placed on the consideration of experimental data which are in agreement with or in contradiction to Mr. Schnadt's theories.

Future work of the Commission

The Commission decided to review the whole field of its activities and at the suggestion of Mr. Audigé (France), set up Working Groups charged with the task of reviewing the work accomplished in the various fields of activity of the Commission. The reports produced by these Working Groups will primarily be a presentation of factual data and interpretation will form a separate section of each report.

The following Working Groups were set up:

Wide plate tests
Professor Kihara (Japan)—Chairman
Professor Hall (U.S.A.)
Professor Soete (Belgium)
Dr. Wells (United Kingdom)

Measurement of residual stresses and strains
Dr. Gunnert (Sweden)—Chairman
Dr. Bihet (Belgium)
Mr. Tummers (Netherlands)

Methods of stress relieving and their efficiency
Mr. Tummers (Netherlands)—Chairman
Dr. Bihet (Belgium)
Dr. Ruge (Germany)

Influence of residual stresses on fatigue strength
Professor Soete (Belgium)—Chairman
Mr. Audigé (France)
Mr. Gurney (United Kingdom)
Professor Hall (U.S.A.)
Professor Louis (Belgium)
Dr. Ruge (Germany)

Professor Louis' Working Group is also to prepare a report on the problem of instability. All these Working Groups were requested to prepare interim reports for the meeting in Oslo.

Appendix

The following documents, in addition to those mentioned in the present report, were circulated to the Commission:

X–261–61—Effect of Notch Shape on Brittle Fracture Strength of Welded Steel Plate, by H. Oba and H. Kihara (Japan)
X–262–61—Effect of Residual Stress on the Initiation and Propagation of Brittle Fracture, by K. Iida, T. Kusuda, K. Narita, A. Takeuchi and H. Kihara (Japan)
X–263–61—Effect of Residual Stresses on the Behaviour of Brittle Fracture Propagation, by K. Iida, T. Kusuda, T. Matsuoka, T. Maeda and H. Kihara (Japan)
X–264–61—Propagation Characteristics of Cracks in the Welded Zone of Quenched and Tempered High Tensile Steel, by T. Nakai and S. Yamauchi (Japan)
X–265–61—A proposal concerning Brittle Crack Propagation Test, by H. Oba (Japan)
X–266–61—A Study of Restraint and Residual Welding Stress on Groove Welded Joint, by H. Onoue, T. Abe and T. Yoshida (Japan)
X–267–61—On the Residual Stresses due to Spot Heating, by H. Kihara and others (Japan)
X–269–61—Effect of High Temperature Prestraining on Retained Ductility of Steel, by K. Terazawa and others (Japan)
X–270–61—Effect of High Temperature Prestraining on Notch Toughness of Steel, by K. Terazawa and others (Japan)
X–274–61—The Brittle Fracture Strengths of Welded Steel Plates: Tests on Five Further Steels (B.W.R.A. Report B6/1/58), by Dr. A. A. Wells (United Kingdom)
X–275–61—Stress Relief of Butt Welds in Rectangular Plates by Local Heating (B.W.R.A. Report B6/6/60), by B. Cotterell (United Kingdom)
X–276–61—Brittle Fracture Strengths of Welded and Notched Three Inch Thick Steel Plates (B.W.R.A. Report B7/4/60), by Dr. A. A. Wells (United Kingdom)
X–277–61—Static Brittle Fracture Initiation without Residual Stresses, by C. Mylonas (U.S.A.)
X–281–61—On the Embrittling Potency of the Residual Stresses existing in Butt Welds, by H. Schnadt (Switzerland).

Commission XI: PRESSURE VESSELS, BOILERS AND PIPELINES

(*Chairman—Mr. J. J. P. Cattel*—Netherlands)

Delegates from the following countries attended the meetings of Commission XI held on the occasion of the Annual Assembly of the IIW at New York in 1961: Belgium, France, Italy, Japan, Netherlands, Sweden, United Kingdom and United States. The delegates were assisted by 16 experts, while in addition nine observers attended the meetings.

Because the Assembly took place outside Europe, the number of delegates, experts and observers and the number of member countries represented was lower than usual for meetings in Europe. This small drawback, however, was more than compensated by the presence at the meetings of a great number of prominent representatives from the United States, which provided an opportunity for intensifying the discussions and increasing mutual understanding within the framework of the activities of the IIW.

As the Chairman of Commission XI, Mr. Cattel, was unable to go to New York, the Vice-Chairman, Mr. Sluis (Netherlands), presided at the meetings.

The Commission had not held any intermediary meetings since the 1960 Annual Assembly at Liège.

Sub-commission B "Allowable Stresses" held an intermediary meeting at Ghent in January 1961, whilst Sub-commission A "Design Details" and the three working groups continued their work by correspondence, without holding any intermediary meetings.

Sub-commission A "Design details"

The last meeting of Sub-commission A was held in London in February 1960, when the main subject discussed was "Recommended welded connections for pipe works". At that time, collated proposals received from ten countries were considered and a fair measure of agreement was obtained. Where no substantial agreement could be reached, the delegates were asked to report back to their national committees for further study and comments. These comments have now been received and will be considered at a meeting which it is proposed to hold in the autumn of 1961. An important point which has arisen in connection with these comments is what distinction, if any, should be made between pipe work intended for low and high duty service and where the limit should be drawn.

Proposals regarding design details for clad steel vessels (Document XI–A–8–60) by Mr. Gerbeaux (France) have been distributed for study and future discussion within the Sub-commission.

The report of Sub-commission A presented at New York brought up the question whether the special subject of long-distance transmission pipelines should fall within the terms of reference of Sub-commission A or Sub-commission B. The U.S.A. delegation stated that this special subject should of necessity be separated from that of piping systems of a confined or integrated nature, such as steam, power or refrigerant system, and suggested that it should be considered by personnel acquainted with the specific problems encountered. It was for this reason proposed that the subject of long-distance pipelines should fall within the terms of reference of neither Sub-commission A nor Sub-commission B, but might be entrusted to a new and separate Sub-commission.

The Chairman of Sub-commission A being absent, discussion of this proposal was postponed until next year's meeting.

Sub-commission B "Allowable stresses"

The work presented and reported on at the New York meeting was based on Document IIW/IIS–9–58 "A Rational Design Procedure for Pressure Vessels" and concerned the following Documents:

XI–59–61 "Design against excessive plastic deformation" by M. J. Bottema (Netherlands)
XI–58–61 "Summary of Document XI–59–61" by Sub-commission B
XI–44–60 "La Corrosion de l'Acier sous contrainte" ("The stress corrosion of steel") by H. Gerbeaux
XI–61–61 "La Corrosion fissurante", Résumé du Document XI–44–60 ("Stress Corrosion Cracking", Summary of Document XI–44–60, "The stress corrosion of steel") by H. Gerbeaux
XI–42–60 "Classement des contraintes en trois catégories" ("Classifying stresses into three classes") by M. Hubert (France)

XI–60–61 "Classement des contraintes en trois catégories" Sommaire du document XI–42–60
(Summary of Document XI–42–60 "Classifying stresses into three classes")
by Sub-commission B

XI–41–60 "Welding of reservoirs and pipelines in winter conditions"
by M. P. Anuckin (U.S.S.R.)

Furthermore, Sub-commission B is looking forward to receiving from Germany a first draft on the subject "Design against excessive elastic deformation" and from the U.S.S.R. a second draft on the subject "Design against corrosion fatigue".

After discussion at New York, Documents XI–58–61, –59–61, –42–61 and –60–61 were referred back to Sub-commission B for further study and consideration in the light of the work in hand on these subjects in the U.S.A., a progress report of which may be made available for the information of Sub-commission B.

In connection with Documents XI–44–60 and XI–61–61, it was decided to ask for the opinion and comments of Commission IX (Behaviour of Metal Subjected to Welding) before considering any further steps regarding their publication. It was furthermore proposed that Document XI–41–60, which had been referred by the main Commission to Sub-commission B during the 1960 meeting at Liège, should now be transmitted to Commissions II (Arc Welding) and IX (Behaviour of Metals Subjected to Welding), as it is considered to fall outside the terms of reference of Commission XI. Two resolutions to this effect were transmitted to the Governing Council and were adopted.

Sub-commission B will continue its work on the basis of Document IIW/IIS–9–58 and hopes to get additional information on the subject of high strain fatigue from the U.S.A. and on excessive elastic deformation and corrosion fatigue from Germany and the U.S.S.R. respectively.

Working Group "Non-destructive inspection of pressure vessels and boilers—testing, measurement and control of welds"

The Chairman of this joint working group with Commission V, Mr. Herpol (Belgium), presented at New York Document XI–57–61 "Radiography of welds of boilers and pressure vessels (Part I: Principles)", this being a revised and completed version of the first draft on this subject.

In the course of the discussion in the main Commission, a certain number of detailed comments from the U.S.A. were dealt with and led to some revisions in the document.

The revised document was recommended for publication as a class B Document, with the object of collecting comments. The Governing Council adopted a resolution to this effect, which was transmitted to it.

In the meantime, the working group will proceed with the preparation of a draft of the second part, dealing with the detailed application of the principles.

Working Group "Stress relieving of pressure vessels and boilers"

The Chairman of this working group, Mr. Gerbeaux, reported at New York on new information gained since the publication of Document XI–45–60 "On the desirability of stress relieving in welded pressure vessels"/"Sur l'opportunité de la relaxation des contraintes dans les appareils à pression soudés".

This new information concerns especially the quality of steel required in relation to the danger of brittle fracture. Mention was made of German investigations regarding the DAST method, applying the ideas of Professor Kloppel, of which Professor Rühl (Germany) gave a summary at Liège last year. The present views of Commission XV (Fundamentals of Design and Fabrication for Welding), which, under the chairmanship of Dr. Guerrera (Italy), also deals with this subject, were made known. These investigations seem to confirm the ratios for Charpy V-values proposed in Document XI–45–60.

After discussion, the working group was asked to continue its work with the object of presenting a new report next year, taking into account the work of Commission XV and the various comments made in the course of the discussions. It was furthermore decided to ask Commission XV to make its present information on this subject available to Commission XI, even if its discussions in this connection have not yet been concluded.

Working Group "Design practice"

It was decided at Liège that this working group should revise and complete its preliminary Document XI–46–60, giving a comparison of the design practice for shells and heads in four countries, using the yield point or 0·2% proof stress as a design basis.

It was pointed out that, in the preliminary draft, too many variables were involved to make any valid comparison of the results. A change was then made in the system, but it was not possible to work out the details in time for a document to be presented at New York.

In the meantime, an excellent paper on the subject of the comparison of design methods and codes was presented and published by Lanchester (Symposium on Pressure Vessel Design of the Institute of Mechanical Engineers, London 1961); because of this the question was raised whether there is still any need for a document of the kind that the working group "Design Practice" is preparing.

It was decided that the working group would continue to compile a document containing the information so far collected, which would be submitted to the main Commission for consideration; it would not, however, go any further into the matter than to round off the information already available.

Survey of the activities of Commission XI

A survey of activities covering the years 1948–58 is contained in Document XI–56–60 by Mr. M. J. Bottema, which is an improved version of the draft Document XI–47–60 and was presented at New York.

It shows that the study of many of the subjects dealt with by Commission XI is not completed, and that the results are not compiled in such a way as to make them easily available to those interested. It was considered most important, for the sake of continuity of facilitating the work of new delegates and of ensuring that the vast amount of valuable information which has been collected and discussed over the course of time is available when the new subjects and points of view which are continually arising are studied, that a more satisfactory way of recording the results of the Commission's work should be found.

To this effect, it was decided that a "task force", consisting of Messrs. Bottema and Spijkers (Netherlands), would review the work surveyed in document XI–56–60 and make recommendations for further steps to be taken. At the same time, they would be asked to relist all Commission XI Documents, classifying them by subject, instead of in chronological order. It was thought that the work of Commission XI would in this way be facilitated.

Lectures on "High pressure pipelines and penstocks" at the 1962 Assembly in Oslo

During the New York Assembly, the French delegation on Commission XI promised a contribution on penstocks, while the U.S.A. delegation promised a lecture and lecturer on the subject of long-distance transmission pipelines. Professor Rykalin (U.S.S.R.) had already agreed previously to obtain contributions from the U.S.S.R., which would probably take the form of two lectures on the subject of long-distance pipelines (efficient methods and rational organisation of welding).

The names of the lecturers and the titles and subjects of their lectures were to have been made available to Commission XI and Mr. Lamp of the Norwegian delegation.

Chairmanship of Commission XI

As the present Chairman of Commission XI, Mr. Cattel, has expressed his wish to resign, it will be necessary for a new Chairman to be appointed at the meeting at Oslo next year.

For this reason, the President of the IIW, Mr. Edström, approached the Commission during the New York meetings, to obtain its suggestions. France, Sweden and the U.S.A. proposed the present Vice-Chairman, Mr. Sluis, and no further proposals were made by the other delegations present. The Executive Council of the IIW will be informed of the Commission's views on this subject.

At the end of the New York meeting, Mr. Hubert distributed and commented upon a document entitled "*Avancement des travaux français sur les contraintes dans les fonds elliptiques ou hémisphériques des réservoirs à pression*" (Progress of French work on stresses in elliptical and hemispherical drum heads of pressure vessels). This Document will be translated into English and will be numbered and circulated as a Commission Document by the Secretariat of Commission XI.

Commission XIII: FATIGUE TESTING

(*Chairman—H. de Leiris*—France)

The field of activity of Commission XIII being fatigue testing, which is normally a time-consuming occupation, and requires very long tests, the unusually short interval between the Liège (1960) and New York (1961) Assemblies could not but result in a reduction, by comparison with former Assemblies, in the total volume of results obtained by the Commission. Two facts are characteristic of this reduction; firstly, all the items on the agenda for the New York meetings, will, in principle, remain on that for the 1962 meetings, as no final conclusions were reached on any of the questions raised; secondly, the number of documents having received a Commission XIII number between Liège and New York was only 26, compared with 33 between Opatija and Liège.

This does not, however, mean that the Commission was inactive during this period. Had this been the case, it would not have been in a position to recommend for publication, as a result of the inquiry opened in March 1954 on *fatigue failures in service*; the following five documents:

Failure of a stainless steel vessel for the recovery of carbon monoxide (Resolution 1)
Failure of the loading beam of a testing machine (Resolution 2)
Failures of connecting rods of motors (Resolution 3)
Failure of a motor crankshaft reclaimed by local welding (Resolution 4)
Failure of the intermediate shaft of a ship's diesel motor (Resolution 5).

Although, unfortunately, the countries represented on the Commission do not all contribute equally the success of this inquiry, the basic questionnaire of which was revised last year as Document XIII–302–60, has again been confirmed. This success is shown not only by the contributions received, but also by the requests for additional information arising from certain of the documents published, and the Commission has had to consider how to meet these requests, whilst preserving the anonymity formally guaranteed to the authors of the documents.

The success of the inquiry on fatigue failures is also evident from the use made of it by Commission XIV "Welding Instruction" of the International Institute, for purposes of instruction; the classification, envisaged (Document XIV–142–61) by Commission XIV, of the failures described by Commission XIII in the light of their various possible causes, has received, save for a few details, the complete agreement of the authors of the documents published. Commission XIII is now seeing, with justifiable satisfaction, how, in this way, the work which it has been carrying out with much perseverance for so many years is bearing fruit.

No less perseverance has been shown in the organisation of *comparative tests on butt welded joints* prepared in different works, tests which the Commission had hoped to complete in time for the 1961 Assembly, if the latter had not been put forward to April. Unforeseen circumstances, such as the holding up of the necessary plates by a strike in the Port of London, also delayed the tests; at the present time, however, these are going well in most countries and have even been completed in some of them. The results, like those of the preceding tests, will be co-ordinated, and described in a single report by the same reporter and it has been agreed that the laboratories taking part should retain the testpieces for possible checking, which may prove to be necessary after analysis of the results by the reporter.

The shortage of time has, however, shown itself in the examination of *the influence of various building-up processes on fatigue strength;* although tests were carried out in several countries, no report has been submitted to the Commission this year.

The situation is much the same as regards the inquiry on the *frequency distributions of the stresses (or loads) in constructions in service*. Nevertheless, certain firm promises of contributions have been made this year, in particular by the American delegation, and it is hoped that this inquiry will soon enter an active phase. Consequently, at the present time, the Commission is concerned with the problem of the significance of the results when measured stresses are obtained either in terms of stress range, or alternatively, in terms of the exceedence of given stress levels: without taking up a firm position on this point, it is possible that the first method of recording is more suited to cases where high endurances are anticipated and the second for limited endurances.

For the evaluation of the fatigue limit using a single test-piece, the Locati method, which was the subject of a paper, Commission XIII was asked to prepare for the 1961 annual meeting of the American Welding Society (R. Cazaud and H. de Leiris "Evaluation of the fatigue limit of welded steel assemblies using a single welded specimen or test element") has produced some extremely encouraging results on widely differing welded steel assemblies. It seems, therefore, that this method could be developed for these assemblies—with all necessary discretion—when the sole purpose is to determine the fatigue limit.

In particular, this method was envisaged by the Commission in connection with the proposed researches into the *influence of weld defects on fatigue strength*: in this instance, the Locati method would not only reduce the length of the tests, but also give an individual evaluation of the strength of each testpiece in conditions of stress which would be identical for each one; consequently, the dispersion affecting this strength for a given type of defect could be estimated. In spite of the advantages it must, nevertheless, be recognised that this method gives no indication of the endurance for loads exceeding the fatigue limit, a disadvantage if comparisons must be made with the rules for construction which fix the stresses admissible for a whole range of endurances. The final choice between the various possible testing methods cannot be made until a detailed examination of the programmes corresponding to each method has taken place so that the amount of work involved in the tests can be calculated and compared with the contributions which can be obtained.

As these contributions do not seem likely to be very considerable, the Commission has resolved to limit itself for the moment to slag inclusions and lack of penetration—and in particular the former—it seems possible to reproduce in a relatively reliable way by processes developed by the British Welding Research Association.

There is also the question of whether it would be possible to use the Locati method for the study of treatment by *local heating or local mechanical compression*. Certain tests described in the paper mentioned above give a favourable indication, but the question is by no means settled. It will doubtless be possible to form more definite conclusions when the time comes for carrying out cooperative research work. In most countries, work is, for the moment, still in a preparatory phase, during which a certain experience is being gained of the various processes which make possible the formation of favourable residual stresses, and, as a result, a certain confidence in these processes is acquired. More systematic research is, nevertheless, at present in hand, not only in Czechoslovakia where Professor Puchner, the first to recommend the process, has just stated the present position (O. Puchner—Influence of induced internal stresses on the endurance limit—Czechoslovak Heavy Industry 1961 No. 1), but also in Great Britain where work is being carried out, firstly, on a theoretical basis, in relation to the determination of the induced stress system and, secondly, on a technological basis, to study the possible use of induction heating equipment. When this work has been successfully completed, the way will doubtless be clear for useful cooperative research on concrete applications.

Finally, if, at New York, Commission XIII hardly touched on new subjects, the work was nevertheless usefully pursued and made better known on the other side of the Atlantic.

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Outside back cover

BRITISH WELDING JOURNAL

INDEX

Volume 8 1961

ADDIE, J.W.
biographical note, 189
mild steel electrodes for contact welding, 135
ADHESION TEST for metallized surfaces, 161
AGEING, effect on mechanical properties, 278
ALLEN, J.S., welded Maidenhead Bridge, 304
ALLOY STEEL
low: cracking prevention, 540; medium-carbon, weldability and transformation, 93; welds, hot cracking in, 526
ALUMINIUM
butt joints, edge preparation for, 220
chemical equipment, design, 237
cleaning, 218
cracking, control of, 229
distortion, 245
ductility at low temperatures, 243
edge preparation, 218, 245
effect on cracking, 535
fusion-welded joints, X-ray inspection, 87s
fusion-welded pressure vessels, specification, 207
inert-gas metal-arc welding, 216, 245
inspection and tests, 211
oxide inclusions in, 231
oxide removal, 218
plastic deformation at low stresses, 242
porosity control, 230
porosity in welds, 314
pressure welding by rolling at elevated temperatures, 377
radiographic exposure techniques, 256
radiography of welds, 208, 253
spray coatings, adhesion test, 161
tungsten-argonarc welding practice, 245
weldability, 310
welded structures, design, 199
welding defects, 229
welding handbook (book review), 206
welding methods and applications, 425
welds: defects and their repair, 249; factors influencing properties of, 227; heat-affected zone, 231; hydrogen in, 314; mechanical properties, 235; properties at sub-zero temperatures, 236; standards of quality, 225
ALUMINIUM ALLOYS
cracking sensitivity, 251
fatigue strength of butt joints, 402
filler metal composition for, 568
fusion-welded joints, X-ray inspection, 87s
fusion-welded pressure vessels, specification, 207
inspection and tests, 211
radiography of welds, 208, 253
stud welding, 116
welding methods and applications, 425
ALUMINIUM-MAGNESIUM ALLOYS, filler compositions for, 571
ALUMINIUM-MAGNESIUM-SILICON ALLOYS, filler compositions for, 573
ALUMINIUM-MAGNESIUM-ZINC ALLOYS, filler compositions for, 360, 573
ALUMINIUM-MANGANESE ALLOYS, filler compositions for, 571
ARC STABILISER, for Al welding, 248
ARC WELDING
argonarc, of sheet, hot-cracking test on, 514
automatic, 141, 159
automatic tungsten-arc, of heat exchangers, 141
current sources, characteristics of, 29s
inert-gas metal-arc: A/CO_2 shielded, of mild steel, 151; of Al, 216, 245; without preheat, of Cu, 353
inert-gas shielded, in Russia, 21
open-arc, 15
practice, 513
report of commission, 18s, 91s
Russia, 19
self-adjusting, A-N mixtures for Cu, 349
special processes, report of Commission, 44s
submerged-arc, 15
tungsten - argonarc, of Al, 245
ARGON/CO_2 mixtures for metal-arc welding, 151
ARMCO IRON, pressure welding by rolling at elevated temperatures, 378
ARSENIC, effect on cracking, 534
AUGLAND, B., biographical note, 504
AUGLAND, B., and CHRISTENSEN, N., notch toughness of submerged-arc weld deposits, 473
AUSTENITIC-FERRITIC transition joints, 469
AUSTENITIC STEEL
cracking in heat-affected zone during heat treatment, 579
cracking in heat-affected zone during welding, 575
pipe, 468
rotors, 464
AUTOMATIC WELDING, developments, 149; see also ARC WELDING

BAGNALL, J.W., obituary, 368
BAILEY, J.C., and ELDRIDGE, G.W., factors influencing properties of welds in aluminium, 227
BAINBRIDGE, C.G., practical welding repairs (book review), 187
BAKER, B.H., biographical note, 284
BAKER, B.H., CREVIS, N., LUCEY, J.A., and LUNAU, F.W., mild steel welding with argon/CO_2 mixtures, 151
BAKER, R.G., see Tremlett, H.F.; Younger, R.N.
BANKS, S.R., biographical note, 284
BANKS, S.R., and SMITH, R.E., design considerations for welded aluminium, 199
BARTLE, P.M., metallurgist in fabrication, 524
BELL, G.R., recent developments in brazing, 166
BEYNER, welded Maidenhead Bridge, 308

BIGGS, W.D., brittle fracture of steel (book review), 92
BIRKHEAD, M., metallurgist in fabrication, 522
BLACKBURN, R.E., obituary, 554
BOILERS, report of Commission, 43s, 101s
BOLTON, W.
biographical note, 69
residual stress distribution in and around spot welds, 57
BONDY, O., welded Maidenhead Bridge, 307
BOON, E.F., biographical note, 285
BOON, E.F., and VAN BERKEL, F.C.A.A., design of chemical equipment in aluminium, 237
BORLAND, J.C.
effect of oxygen and nitrogen on properties of welds in unalloyed titanium 61
hot cracking in mild and low alloy steel welds, 526
see also Younger, R.N.
BOWRING, F.B., Lloyd's Register requirements in testing of welders, 1
BOYD, G.M.
metallurgical concomitants of residual stress, 343
welded Maidenhead Bridge, 308
BRAITHWAITE, R.G.
metallurgist in fabrication, 522
welded Maidenhead Bridge, 309
BRAZING, developments in, 166
BRESLER, B., and LIN, T.Y., design of steel structures (book review), 412
BRIDGE, Maidenhead, 291
BRITISH WELDING RESEARCH ASSOCIATION
staff appointments, 193
wire speed measurement, 590
BRITTLE FRACTURE
mild steel pressure vessels, 561
pressure vessels, 32s
service, co-operative study of, 67s
steel, 92 (book review)
strength of welded steel plates, 259, 412
strengths of welded and notched 3 in. thick plate, 389
BROZZO, P., results of torsion relaxation tests, 79s
BURGESS, N.T.
automatic tungsten-arc welding of heat exchangers, 141
metallurgist in fabrication, 523
BUSSE, F.
biographical note, 189
foil seam welding, 123
BUTT JOINTS
Al, edge preparation for, 220
fatigue strength of, in H15 Alloy welded with Cusil 73 filler wire, 402
BUTT WELDING
steam pipes, 466
tube in dissimilar metals, 466
BUTT WELDS
Al-alloy, fatigue strength of, 402
in plate, stress relief of, 485

CAPEL, L.
aluminium welding practice, 245
biographical note, 285
CAPPER, welded Maidenhead Bridge, 308
CARBON, effect on cracking, 532
CARBON DIOXIDE, see Argon/CO_2
CHADWICK, A., obituary, 503
CHEMICAL EQUIPMENT, Al, design of, 237
CHRISTENSEN, N., see Augland, B.
CHROMIUM, effect on cracking, 537
CLACK, V.W., training the welding technician, 51s
CLEANING, Al, 218
CLEWS, K.J., inert - gas - shielded metal-arc welding of thick copper without preheat, 353
COATING(S) metallized, adhesion test, 161
plastic, division of Institute, 388, 414, 457, 502
see also METAL SPRAYING; SPRAYING
COLTON, W.J., metallurgist in fabrication, 523
COMBUSTION, iron-oxygen, in gas cutting, 79
CONDENSERS, welding, 149
CONNECTING ROD, fracture of, 83a
CONTACT WELDING, mild-steel electrodes for, 135
CONTINUOUS COOLING TRANSFORMATION, characteristics determination, 95
COPPER
effect on cracking, 537
inert-gas shielded metal-arc welding without preheat, 353
self-adjusting arc welding, A-N mixtures for, 349
welding methods and applications, 420
COPPER ALLOYS, welding methods and applications, 420
CORROSION FATIGUE, in oil engines, 13
COTTERELL, B., stress relief of butt welds in rectangular plates by local heating, 485
CRACKING
Al, control of, 229
arrest edge effect, 274
arrestors, in ship construction, 45
effect of elements, 531
fatigue, of main deck of warship, 5s
filler materials for Al-Zn-Mg alloys, 362
heat-affected zone, in austenitic steels during welding, 575
heat-affected zone, in austenitic steels during heat treatment, 579
hot, in mild and low alloy steel welds, 526
intergranular precipitation and, 585
iron-binary systems, 529
mechanism of, 578
oxide films in spot welding, 411
prevention, 586
prevention in mild and alloy steel, 539, 540
sensitivity of Al alloys, 251
stress-corrosion, 26
theory, 526
see also FRACTURE
CRACKING TESTS
BWRA, 575, 579
hot, on sheet during argonarc welding, 514
wedge, 93
CRACKNELL, A., brittle fracture of mild steel pressure vessels, 561
CRANKSHAFT, web fracture, 85s
CREVIS, N., biographical note, 284
see also BAKER, B.H.
CUSIL 73 FILLER WIRE, H15 alloy welded with, fatigue strength of butt joints in, 402
CURRENT SOURCES, for arc welding and cutting, 29s
CUTTING
characteristics of current sources for, 29s
gas, iron-oxygen combustion in, 79
oxygen, research report, 86
Russia, 22

DAVY, C.H., Vice President, 414
DERRY, L.W., see Johnston, R.D.
DESIGN
and fabrication for welding, fundamentals of 49s
of steel structures (book review), 412
DINSDALE, W.O., and NEWMAN, R.P., fatigue strength of butt joints in H15 alloy welded with Cusil-73, 402
DISSIMILAR METALS, butt welding of tubes in, 466
DISTORTION
Al, 245
in oil engines, 13
DIXON, H.E., metallurgist in fabrication, 520, 525
DOCUMENTATION, report of Commission, 23s, 96s
DORRAT, J.A.
biographical note, 31
welding in production of marine oil engines, 10
DUCTILITY, weld metal, influence of storage time, 172

EASTWOOD, F.A., obituary, 503
EDGE PREPARATION
Al, 218, 245
Al butt joints, 220
EDUCATION AND TRAINING, 416, 558
Institute of Welding committee, 385

EDUCATION AND TRAINING (cont.)
post-graduate course, 258
report of Commission, 48s
welding technician, 51s
welding technology, conference, 384
see also SCHOOL OF WELDING TECHNOLOGY
ELDRIDGE, G.W., see Bailey, J.C.
ELECTRO-SLAG WELDING, in Russia, 21
ELECTRODES
effect on brittle-fracture strength of plate, 271
mild steel, for contact welding, 135
wire speed measurement, 590
EXPANSION BELLOWS, welding, 471

FABRICATION for welding, design and, fundamentals of, 49s
FATIGUE
corrosion, in oil engines, 13
cracking of main deck of warship, 5s
failure: in bottom plating, 70s; bulkhead stringers, 8s; hoist, 4s; IIW enquiry on, 16s; reports on, 1s, 70z, 83s
fracture: axle of trailer, 13s; drive shaft of rolling mill reduction gear, 14s
oil engines, 12
ship construction, 8s
strength of butt joints in H15 Alloy welded with Cusil 73 filler wire, 402
strength of fillet welded joints in mild steel, influence of artificially induced residual stress on, 541
FATIGUE TESTING, report of Commission, 46s, 103s
FEED-WATER HEATERS
automatic tungsten-arc welding of, 141
welded steel tubes, 470
FERRITIC STEEL, pipe, 468
FILLER MATERIALS, for Al-Zn-Mg alloys, 360
FILLER METAL
for Al, 235
for Al alloys, 568
FILLER WIRE, Cusil 73, fatigue strength of butt joints in H15 alloy welded with, 402
FILLET JOINTS, in mild steel, influence of artificially induced residual stress on fatigue strength, 541
FILMS, oxide, cracking in spot welding, 411
FITCH, I.C., metallurgist in fabrication, 523
FLAME SPRAYING, see Spraying
FLEET, C., obituary, 554
FOIL, seam welding, 123
FOWLER, R.J., welded Maidenhead Bridge, 303
FRACTURE
brittle, see BRITTLE FRACTURE
fatigue, see FATIGUE
lorry frame longitudinal member, 77s
ship construction, 44
welded water tanks of locomotive tenders, 75s
see also CRACKING
FREEMAN, welded Maidenhead Bridge, 308
FRICTION WELDING, in Russia, 22
FUCHS, E.
metallurgist in fabrication, 525
quality in welding, 4
FUSION JOINTS, X-ray inspection, 87s

GAS CUTTING, see Cutting
GAS WELDING
report of Commission, 17s
Russia, 22
GLINER, B.M., determination of the mechanical and technological properties of metals (book review), 436
GRAELY, J.W., obituary, 368
GRAHAM, W., obituary, 503
GRAIN GROWTH
mild-steel weld metal, 453
refinement and, 344
GREENWOOD, J.A.
biographical note, 336
temperatures in spot welding, 316
GURNEY, T.R., influence of artificially induced residual stresses on fatigue strength of load carrying fillet welded joints in mild steel, 541

HEAT-AFFECTED ZONE
Al welds, 231
cracking in austenitic steels during heat treatment, 579
cracking in, of austenitic steels during welding, 575
metallography, 580, 583
HEAT-EXCHANGER TUBES, welding fins to, 472
HEAT-EXCHANGERS, automatic tungsten arc welding, 141
HEAT-RESISTING STEELS, torsion relaxation tests, 79s
HEAT-TREATMENT, heat-affected zone cracking in austenitic steels, 579
HEATERS, feed-water, automatic tungsten-arc welding of, 141
HINDE, J., metallurgist in fabrication, 522
HOIST, fatigue failure, 4s
HOPE, W.F., obituary, 31
HOULDCROFT, P.T., investigation of filler materials for welding Al-Zn-Mg alloys, 360
HULLS, welded, structural and metallurgical requirements, 43
HUNTER, N.M., welded hulls, 49
HUXLEY, H.V., determination of hot crack susceptibility of steel sheet during argonarc welding, 514
HYDROGEN
Al welds, 314
control in weld metal, 94
HYGIENE, see SAFETY AND HEALTH

INCLUSIONS, oxide, in Al, 231
INGLIS, N.P., and TAYLOR, E.A., welding in non-ferrous field, 419
INSPECTION AND TESTING
Al and Al-alloy welds, 253
Al and Al-alloys, 211
oil engines, 17
quality control, 315
welds, C.E.G.B. research, 150
see also under specific methods and items tested
see also under specific methods
INSTITUTE OF WELDING
annual dinner (1960), 30
annual general meeting (1961), 457
autumn meeting (1960), 30, 520
awards, 385
balance sheet, 386
branch activities, 388 (see also below)
co-operation with other bodies, 388
Council nominations, 283
Education Committee, 385
election of members, 68, 188, 283, 335, 458, 503, 554, 588
finances, 388
honorary officers and Council, 384
income and expenditure account, 387
joint meeting with Institution of Metallurgists, 520
joint meeting with Netherlands Welding Society, 366
Larke Medal award, 188
library and information service, 388
membership figures, 388
metal spraying and plastic coating division, 388, 414, 457, 502
premises, 388
Presidential Address, by E.Fuchs, 4
publications, 31, 104, 189, 367, 384
report of Council (1960), 384
spring meeting (1961), 335
symposium on welding in shipbuilding, 477, 588
technical committees, 385
Tibbenham prizes, 31
see also SCHOOL OF WELDING TECHNOLOGY

Branch news:
Birmingham, 69, 191, 589
East Midlands, 32, 69, 105, 191, 285, 368, 458, 461*
East of Scotland, 32, 70, 191, 286,

Branch news:East of Scotland(cont.)
336, 460, 461*, 504
Eastern Counties, 461*
Leeds, 105, 460, 461*
Liverpool, 369, 4'6,458,460, 461*, 482
Manchester, 32, 70, 105, 192, 286, 336, 369, 460, 461*, 589
North Eastern (Tees-side), 461*, 504, 555
North Eastern (Tyneside), 70, 336, 460, 461*, 555
North London, 32, 70, 106,192,337, 460, 461*, 590
Slough Section, 555
Preston, 461*
Sheffield, 32, 106, 286, 460, 461*
South London, 71, 106, 291, 337, 455, 462*, 555, 590
Medway Section, 462*
South Wales, 337, 462*
South Western, 34, 71, 106, 192, 286, 337, 369, 461, 462*, 555
Southern Counties, 33, 462*, 505
West of Scotland, 34, 107, 193, 337, 461, 462*
Wolverhampton, 35, 71, 107, 338, 370, 416, 462*, 505
* indicates Committees for 1961-62

INSTITUTION OF METALLURGISTS, joint meeting with, 520
INTERNATIONAL INSTITUTE OF WELDING
Annual Assembly (1961),107,556,36s
Annual Assembly (1962), 557
annual meeting of Commission chairmen, 193
Cabelka, J., elected Vice - President, 338
enquiry on fatigue failures, 16s
publications, 31
reports of Commissions,17s,37s,91s
reports on fatigue failures, 1s, 70s, 83s
IRON, Armco, see ARMCO IRON
IRON BINARY SYSTEMS,cracking in,529
IRON-OXYGEN COMBUSTION in gas cutting, 79

JOHNSTON, R.D., biographical note, 555
JOHNSTON, R.D.,-and DERRY,L.W., welding behaviour of niobium and vanadium, 511
JONES, C.F., obituary, 105

KERENSKY, O.A., welded Maidenhead Bridge, 308

LANE, P.H.R., and ROSE,R.T., experiments on fabricated pipe bends,323
LAURIE, D.J.N.
biographical note, 190
developments in stud welding,113
LIGHT METALS, welding handbook (book review), 206
LLEWELLYN, D., Honorary Member,414
LLOYD'S REGISTER OF SHIPPING, testing of welders, 1
LOCOMOTIVE TENDERS, water-tank fracture, 75s
LORRY FRAME, fracture, 77s
LUCEY, J.A., see BAKER, B.H.
LUNAU, F.W. biographical note,284
see also Baker, B.H.

MCWILLIAM, J.A., metallurgist in fabrication, 523
MAGNESIUM
fusion-welded joints,X-ray inspection, 87s
pressure welding by rolling at elevated temperatures, 379
welding handbook (book review), 206
MAGNESIUM ALLOYS, fusion - welded joints, X-ray inspection, 87s
MAIDENHEAD BRIDGE, 291
MANGANESE, effect on cracking,532
MANHOLES, in welded storage tanks, 491
MANIPULATORS, use of, 15
MANUEL, L., flame spraying developments, 121
MATTING, A., Das Schweissen der Leichtmetalle und seine Randgebiete (book review), 206
MECHANICAL AND TECHNOLOGICAL PROPERTIES of metals, determination of (book review), 436
METAL SPRAYING
Al, adhesion test, 161
division of Institute of Welding, 388, 414, 457, 502
see also Spraying
METALLURGISTS, role in fabrication involving welding, 520
METALLURGY, mild-steel weld metal, 437
METALS
behaviour of, subjected to welding, report of Commission, 37s
mechanical and technological properties of, determination of (book review) 436
MIG WELDING, see ARC WELDING, inert-gas metal-arc
MILD STEEL
cracking prevention,539
electrodes for contact welding,135
influence of artificially induced residual stress on fatigue strength of fillet welded joints in, 541
pressure vessels, brittle fracture of, 561
weld metals, mechanical properties and metallurgical features of, 437
welding with argon/CO_2 mixtures, 151
welds, hot cracking in, 526
MILLER-WATT, J., obituary, 31
MILNE, C.S., obituary and appreciation, 415
MILNER, D.R., see Nicholas, M.G.
MOLYBDENUM, effect on cracking, 537
MURRAY, J.S., obituary, 105

NEEDHAM, J.C., current sources for special arc welding and cutting processes, 29s
NETHERLANDS WELDING SOCIETY, joint meeting with, 366
NEVILLE, S.W.
metallurgist in fabrication, 523
ultrasonic welding, 177
NEWMAN, R.P., see Dinsdale, W.O.
NEWTON, A.F., obituary, 105
NICHOLAS, M.G.,biographical note,416
NICHOLAS, M.G., and MILNER,D.R., pressure welding by rolling at elevated temperatures, 375
NICKEL
effect on cracking, 535
welding methods and applications, 429
NICKEL ALLOYS, welding methods and applications, 429
NIOBIUM, welding behaviour of,511
NITROGEN, effect in Ti welds, 61
NON-FERROUS METALS, welding, 419
NOTCH-TOUGHNESS, submerged-arc weld deposits, 473
NUCLEAR POWER PLANT, welding in,463

OATES, J.A., modern arc welding practice (book review), 513
OIL ENGINES, marine, welding in, 10
OLDFIELD, G.H., obituary, 105
OXIDE
films, cracking in spot welding,411
inclusions in Al, 231
removal from Al, 218
OXYGEN
effect on cracking, 534
effect in Ti welds, 61
OXYGEN CUTTING, see CUTTING

PALMER, P.J.
biographical note, 69
band reinforced and layer built pressure vessels, 51
PARKINS, R.N., experiments in controlled low temperature stress relief, 24
PARR, F., obituary, 105
PENETRANT TESTS, Al and Al - alloy welds, 255
PFEIFFER, C.,
biographical note, 190
influence of storage time on weld

metal ductility, 172
PHOSPHORUS, effect on cracking, 533
PIPE
austenitic steel, 468
ferritic steel, 468
steam, butt welding, 466
PIPE BENDS, gusseted fabrication of, 323
PIPELINES, report of Commission, 43s, 101s
PLASTIC COATINGS, division of Institute, 388, 414, 457, 502
PLATE
brittle-fracture strength, 259
brittle-fracture strengths of welded and notched 3 in. thick, 389
brittle-fracture strength of welded steel, 412
ship, effect of thickness, 46
stress relief of butt welds in, 485
PLATING, shell, of banana ship, damage to, 1s
POROSITY
Al, control of, 230
Al welds, 314
PRECIPITATION, intergranular, and cracking, 585
PRESSURE VESSELS
band reinforced, 51
brittle fracture in, 32s
fusion-welded Al and Al - alloy, specification, 207
layer built, 51
mild steel, brittle fracture of, 561
report of Commission, 43s, 101s
PRESSURE WELDING, by rolling at elevated temperatures, 375
PRESTON, L.R., obituary, 503

QUALITY
in Russia, 23
in welding, 4
QUALITY CONTROL, 315
in welding, conversazione, 455
QUENCH-AGEING, 346

RADIOGRAPHY
Al and Al-alloy pressure vessels, 215
Al and Al-alloy welds, 253
Al and Al-alloys, 208
Al-alloy butt joints, 403
exposure techniques for Al, 256
image quality indicators, 90s
recommended techniques, 88s
welds, 482
X-ray, on fusion welded joints, 87s
RAILTON, C.L., metallurgist in fabrication, 524
REDSHAW, L., Vice-President, 414
RELAXATION TESTS, torsion, heat-resisting steel, 79s
REPAIRS, welding (book review), 187
RESIDUAL STRESS
artificially induced, influence on fatigue strength of fillet welded joints in mild steel, 541
distribution in spot welds, 57
generation and relief, 24
measurement, 58
metallurgical concomitants, 343
report of Commission, 41s, 99s
RESISTANCE WELDING
report of Commission, 21s, 95s
Russia, 21
ROBERTS, G., welded Maidenhead Bridge, 291, 308
ROBERTSON, J.M.
biographical note, 503
welding in steam, gas turbine, and nuclear power plants, 463
ROLLING, at elevated temperatures, pressure welding by, 375
ROLLING MILL reduction-gear drive-shaft failure, 14s
ROSE, R.T., strength of rim reinforcements for manholes in welded storage tanks, 491
see also Lane, P.H.R.
ROTORS, austenitic steel, 464
RUSSIA, welding mission to, 18

SAFETY AND HEALTH
Al welding, 253
report of Commission, 37s, 98s
SCHOOL OF WELDING TECHNOLOGY
courses, 368, 589
exhibition of non-destructive test equipment, 190
report of council, 385
SCIENTIFIC PROGRAMMING, in business and industry (book review), 140
SEAM WELDING, foil, 123
SHAFTS, fatigue fractures, 86s
SHEET, hot-cracking test, 514
SHIP CONSTRUCTION
damage to shell plating, 1s
effect of plate thickness, 46
fatigue cracking of main deck of warship, 5s
fatigue failure of bottom plating, 70s
fatigue failure of bulkhead stringers, 8s
fractures, 44
welded hulls, 43
SHIPBUILDING, welding in, symposium on, 477, 588
SILICON, effect on cracking, 534
SILVER, welding methods and applications, 431
SKINNER, E. H., obituary, 415
SLATER, D., see Tomlinson, J.E.
SMITH, F.
biographical note, 285
fusion welded aluminium and aluminium alloy pressure vessels, 207
SMITH, R.E., biographical note, 285
see also Banks, S.R.
SMITH, R.S., biographical note, 190
SMITH, R.S., and STEPHENSON, N., adhesion test for aluminium spray coatings and other metallized surfaces, 161
SPOT WELDING
cracking of oxide films in, 411
temperatures in, 316
SPOT WELDS, residual-stress distribution in, 57
SPRAYING
plasma flame, applications, 121
powder, applications, 121
wire, applications, 121
see also METAL SPRAYING
SPRAYING MACHINES, auto-pneumatic, 130
STANDARDIZATION, report of Commission, 26s
STANTON, W.E.
auto-pneumatic metal spraying machines, 130
biographical note, 190
STEAM PIPES, butt welding, 466
STEAM PLANT, welding in, 463
STEEL, specifications, 47
see also under specific types
STEEL STRUCTURES, design of, (book review), 412
STEPHENSON, N., biographical note, 284
see also Smith, R.S.
STEVENSON, R.C., obituary, 503
STORAGE TANKS
manholes in welded, 491
prefabricated, 22
STRAIN, plastic, effect on mechanical properties, 278
STRAIN-AGEING, 344
STRESS ANALYSIS, 27
STRESS-CORROSION, cracks, 26
STRESS-RELIEF
butt welds in plate, 485
controlled low-temperature, 24
effect on mechanical properties, 278
report of Commission, 41s, 99s
STRUCTURES
steel, design of (book review), 412
welded Al, design of, 199
STUD WELDING
Al alloys, 116
developments, 113
SULPEUR, effect on cracking, 532

TANKER, fatigue failure of bulkhead stringers, 8s
TAYLOR, E.A., see INGLIS, N.P.
TECHNOLOGICAL AND MECHANICAL PROPERTIES of metals, determination of (book review), 436
TERMINOLOGY, report of Commission, 26s
TESTING
report of Commission, 24s
welders, 1

see also INSPECTION AND TESTING
THOMAS, J.V., metallurgist in fabrication, 524
TIPPER, C.F.,
biographical note, 285
effect of plastic strains on mechanical properties of five steels, 278; correction, 340
TITANIUM
effect of oxygen and nitrogen in unalloyed welds, 61
welding methods and applications, 431
TOMLINSON, J.E., and SLATER, D., Mig welding techniques for aluminium, 216
TOMS, M.S., brittle fracture strength of welded steel plates, 259
TORSION RELAXATION TESTS, heat-resisting steels, 79s
TRAILER AXLE, fatigue failure, 13s
TRAINING, see EDUCATION
TRANSFORMATION, relationship with weldability, 93
TRANSFORMER, for Al welding, 248
TREMLETT, H.F., BAKER, R.G., and WHEATLEY, J.M., mechanical properties and metallurgical features of mild steel weld metals, 437
TRIPP, J.H., see WILLIAMSON, J.B.P.
TUBE
butt welding in dissimilar metals, 466
heat-exchanger, welding fins to, 472
TURBINES, gas, welding in, 463

ULTRASONIC TESTS, Al and Al-alloy welds, 255
ULTRASONIC WELDING, history and development, 177
URWIN, H.P., welded hulls, 50
USSR, see RUSSIA

VANADIUM, welding behaviour of, 511
VAN BERKEL, F.C.A.A., biographical note, 284
see also Boon, E.F.
VAZSONYI, A., scientific programming in business and industry (book review), 140

WADDINGTON, E.S., obituary and appreciation, 503
WATKINSON, F., welding of medium-carbon low-alloy steels, 93
WEDGE TEST, see CRACKING TESTS
WELD DESPOSITS, submerged-arc, notch toughness of, 473
WELD METAL
ductility, influence of storage time on, 172
hydrogen control, 94
mild steel, mechanical properties and metallurgical features of, 437
WELDABILITY
Al, 310
relationship with transformation, 93
WELDED JOINTS
fillet, in mild steel, influence of artificially induced residual stress on fatigue strength, 541
fusion, X-ray inspection, 87s
see also WELDS and under specific types
WELDED STRUCTURES, Al, design, 199
WELDERS, testing of, 1
WELDING
behavious of metals subjected to, report of Commission, 37s
marine oil engines, 10
non-ferrous metals, 419
quality in, 4
quality of, in Russia, 23
in shipbuilding, symposium on, 477, 588
see also under specific processes and items and materials welded
WELDING ELECTRODES, see ELECTRODES
WELDING INSTRUCTION see EDUCATION AND TRAINING
WELDING MACHINES, automatic, 15
WELDING REPAIRS, (book review), 187
WELDING TECHNICIAN, education and training, 51s
WELDS
measurement and control of, report of Commission, 24s
see also WELDED JOINTS and under specific types
WELLS, A.A.
brittle fracture strength of welded steel plates, 259
brittle fracture strength of welded steel plates (Letter), 412
brittle fracture strengths of welded and notched 3 in. thick steel plates, 389
iron-oxygen combustion in gas cutting, 79
oxygen cutting, 86
pressure vessel brittle fracture and information required to design against it, 32s
WEST, H., President, 414
WESTENDORP, G., weldability of aluminium, 310
WHALLEY, R.B., quality control (Letter), 315
WHEATLEY, J.M., see TREMLETT, H.F.
WHEELER, N.F., obituary, 554
WHITAKER, P., brittle fracture strength of welded steel plates, 259
WILLIAMS, J.G., obituary, 284
WILLIAMSON, J.B.P., and TRIPP, J.H., cracking of oxide films in spot welding, 411
WILLMOUTH, A.T., obituary, 336
WILSON, W.J., obituary, 368

X-RAY INSPECTION, fusion welded joints, 87s

YOUNG, J.G.
argon-nitrogen mixtures for self-adjusting arc welding of copper, 349
filler metal composition in aluminium alloy welding, 568
YOUNG, R.T.
biographical note, 69
development of structural and metallurgical requirements for welded hulls, 43,67
YOUNGER, R.N., and BAKER, R.G., heat affected zone cracking in welded austenitic steels during heat treatment, 579
YOUNGER, R.N., BORLAND, J.C., and BAKER, R.G., heat-affected zone cracking of austenitic steels during welding, 575

ZINC, pressure welding by rolling at elevated temperatures, 379
ZIRCONIUM, welding methods and applications, 435